Chapter 5—Track Components and Materials

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CHAPTER 5—TRACK COMPONENTS AND MATERIALS

5.1 INTRODUCTION

The track components that form the track structure generally include rail, fastenings, crossties, and ballast. This chapter includes these and other sundry components and elaborates on their various designs and requirements.

Many standard track components and other track material (OTM) are usable for freight railway, commuter railway, and heavy transit (metro) systems. The information provided in this chapter pertains to light rail transit systems with overhead catenary or contact wire distribution that use the running rail as a negative return for the traction power system.

5.2 TEE RAIL AND GIRDER GROOVE RAIL

5.2.1 Introduction

Rail is the most important—and most expensive—element of the track structure. It is the point of contact with the vehicle wheel, the structural beam supporting the vehicle load, and one location where noise is generated. Hundreds of different rail sections have been created since the first strip of iron was placed on a timber beam. Each new rail section has been developed to satisfy a particular combination of wheel/rail loading. Tee rails were developed for ballasted track. When rails were placed in streets, girder rails were developed to provide the needed flangeway.

North American tee rail sections have evolved over the years into the current American Railway Engineering and Maintenance of Way Association (AREMA) standards—115 RE, 132 RE, and 136 RE. Many other rail sections are still in use today.

The rail section identification 115 RE refers to:

- 115 = mass (weight) 57.0 kilograms per meter (114.7 pounds per yard).
- RE = AREMA standard rail section.

Rail sections and steel composition continue to evolve and be improved worldwide. The 115 RE rail section is the primary section used on contemporary light rail track systems because it provides a recognized standard section, as well as a guaranteed continuous supply. The 115 RE rail easily supports light rail vehicle loads and has sufficient end area to act as a low-resistance negative return conductor in the traction power circuitry.

The standards for rail lengths have improved from the customary 11.8-meter (39-foot) length to 23.8-, 24.4-, and 25-meter (78, 80 and 82-foot) lengths. European rail mills have recently produced rail in 122-meter (400-foot) lengths. This is not a standard in North American rail mills.

Joints between rails have always been the weak link in the track system. Welding of the rolled rail lengths into continuous welded rail (CWR) is customary to eliminate joints and to improve the performance of rail in track. The development of thermite and flash butt welding allows the track to be constructed in CWR strings. CWR is the general standard for all transit except for locations, such as very sharp precurved track, where jointed rail may be more practical to suit specific site conditions and future maintenance procedures.

Precurving of rail is a requirement on light rail systems at locations where the radii of curved track exceeds the elastic limit of the rail.

The two prime maintenance issues associated with rail are head wear in curves and rail corrugation. These issues are discussed at length in this section.

Girder rail is needed to support rail in streets and to form a flangeway for the wheel. The rail can then have pavement around the rail to allow motor vehicles to share the road with trains. Girder groove rail and girder guard rail sections are no longer manufactured in North America. The popular girder rail sections in use and available from European manufacturers are the Ri 59N, Ri 60N, IC, Ri52N, Ri53N, NP4a, and 35G sections. Previous popular sections no longer available include 128 RE-7A, 149 RE-7A and the GGR-118. There is a limited selection of girder groove rail and girder guard rail in today's market. Few girder rails have the minimal transit flangeway widths, which complicates the issue of railway wheel gauge and track gauge. For additional information on girder rail and flangeways refer to Chapter 4 herein.

Girder groove rail installed to improve track performance should be welded where possible. Girder groove rail requires precurving of rail for nominal radii curved track alignments due to the section.

5.2.2 Tee Rail

The standard section for running rail on contemporary light rail systems for the three types of track structure are generally similar unless specifically stated otherwise.

5.2.2.1 Rail Section - 115 RE or 124 BC

5.2.2.1.1 AREMA Rail Sections

Selection of the running rail section must be performed with consideration for economy, strength, and availability. The current selection in North America is limited and the simplest solution is to select an off-the-shelf 115 RE rail section conforming to AREMA standard rail or high-strength rail requirements. The section has more than adequate beam strength to support the wheel on standard crosstie and direct fixation fastener spacing.

Wheel/rail interface is one of the most important issues in the design of the wheel profile and the railhead section. Contemporary light rail transit systems provide the opportunity to customize design and maintain an optimal wheel/rail interface due to the single standard for wheels and rail

Although rail wear and fatigue are considerations on transit systems, the primary design concerns are: optimizing vehicle operation, controlling noise and vibration, and improving ride quality.

A better understanding of and major improvements to wheel and rail design and interface issues are evolving. The optimized wheel/rail interface (OWRI) system considers both vehicle suspension characteristics and track and rail standards.

Modifications in the rail head radius will improve the current rail profile of AREMA sections. The current 115 RE rail section includes a 254-millimeter (10-inch) crown head radius. To improve the wheel tread to rail contact zone, a 203-millimeter (8-inch) head radius is recommended. This will reduce and control the contact band along the rail to a well-defined 12- to 15-millimeter (1/2- to 5/8-inch) width. Several transit agencies have incorporated more radical improvements, such as asymmetrical rail grindings for outside and inside rail in track curves, with documented operational improvements in wheel/rail performance.

Vehicle performance is based on the primary and secondary suspension systems that allow the vehicle to negotiate curves. The wheel and rail profiles control how well the vehicle truck steers in curves and how much the truck will hunt on tangent track. The concentrated contact zone between the wheel and rail can be positioned at the gauge corner on the high outside rail of curves to improve steering. The contact zone on the low rail is best located toward the field side of the rail head. These positions of the contact zones take advantage of the wheel rolling radius differential and improved axle steering in conical wheels.

Wheel and rail design that produces a conformal contact zone, or wider wear pattern, after a short period of service life exacerbates poor vehicle tracking performance through curved track. It also introduces early wheel hunting and leads to corrugation in the rail head. Conformal contact conditions are produced when the rail head radius is worn to a flat condition and the wheel is worn to a similar flat or hollow condition. This simulates rail head configuration, producing a wear zone across the head of the rail.

The current 115 RE rail section consists of a crown radius of 254 millimeters (10 inches) and gauge corner radii of 38.1 and 9.5 millimeters (1-½ and 3/8 inches). The rail head width is 69.1 millimeters (2-23/32 inches) and the rail height is 168.3 millimeters (6-5/8 inches) as shown in **Figure 5.2.1**. Railroads, including BC Rail, have been searching for an improved rail section or profile—one with increased wear life and performance. Undesirable wear patterns such as gauge corner lip formation and shelling on the standard 136 RE rail section have required early gauge corner and field corner grinding. Dr. J. Kalousek (JK) proposed a 203-millimeter (8-inch) head radius for the standard 136 JK rail section instead of the standard 254-millimeter (10-inch) radius to improve the contact location as previously described.

5.2.2.1.2 124 BC Rail Section

BC Rail, to improve the standard 115 RE rail section and retain the OTM currently in service opted to change the rail head portion of the 115 RE rail section. BC Rail mated the 115 RE rail web and base section to the 136 JK rail head section to create the 124 BC section.[1] The 124 BC rail section provides additional steel in the rail head wear area as shown in Figure 5.2.1.

The 124 BC rail section improves on rail head radius and provides additional rail life due to increased steel in the rail head wear area. A rail section of this size may be especially effective if tee rail is to be used in embedded track where replacement of worn rail is more labor intensive.

An imbalanced track/vehicle system contributes to excessive wear of both the wheel and rail. A combination of wheel/rail vehicle track incompatibilities contribute to high lateral over vertical (L/V) ratios, excessive flanging action, and gauge face wear of more than 20 degrees on the high rails of sharp curves. Corrective rail section design, rail profile grinding, and an effective wheel truing program along with flange-mounted lubricators will improve rail performance, reduce maintenance, and increase rail life. [2]

The transit industry and freight railroads will continue to push for improvements to the current standard rail sections such as standardization of the 124 BC section and a compatible wheel profile. For details on the wheel profile development refer to Chapter 2.

5.2.2.2 Rail Strength—Standard/High-Strength Tee Rail

Chemical composition guidelines for running rail are standardized in the AREMA Manual,

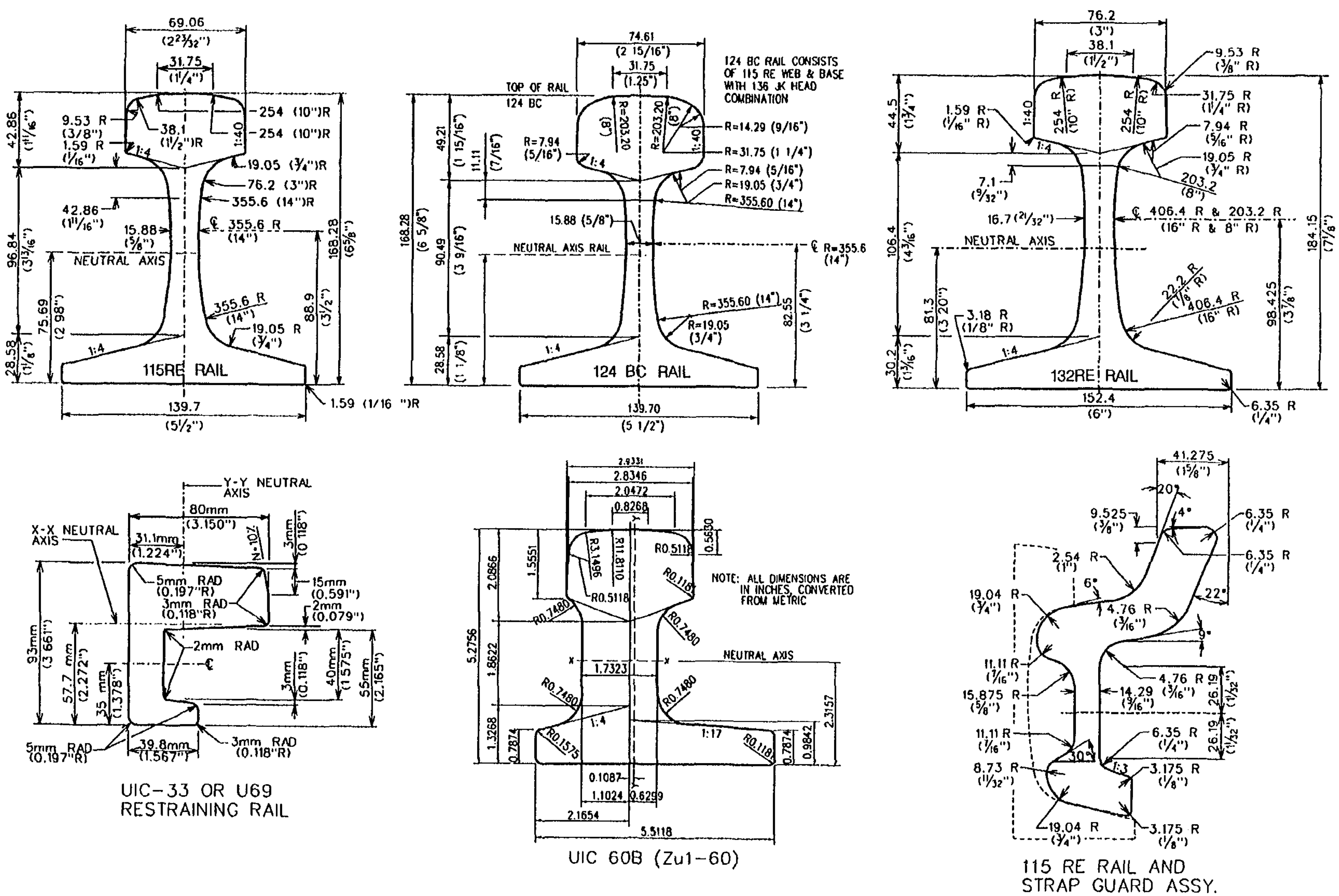


Figure 5.2.1 Typical Rail Sections Tee Rail (U69, 115 RE Strap Guard, ZU 1-60)

Chapter 4, for both standard rail and high-strength rail. The use of alloy rail is not recommended to obtain the high-strength standards because of the additional complexities of welding alloy rail. Current standard and high-strength rail hardness, including the head hardening procedure, obtain the following standards:

- Standard Rail: 300 minimum Brinell Hardness Number (BHN)
- High Strength Rail: 341 to 388 BHN (may be exceeded provided a fully pearlitic microstructure is maintained.)

5.2.2.2.1 Rail Metallurgy[3]

The life of the rail can be extended by increasing the rail's resistance to:

- Wear
- Surface fatigue-damage
- Fatigue defects

Rail steel hardness, cleanliness, and fracture toughness can increase this resistance. The effect of rail hardness in resisting gauge face wear is a known fact. Increased rail hardness in combination with minimized sulfide inclusions reduces the likelihood of surface fatigue cracking. This, in turn, reduces development of subsequent defects such as head checks, flaking, and shelly spots. Oxide inclusion clean steel, combined with good fracture toughness, reduces the likelihood of deep-seated shell formations. Both shelly spots and deep-seated shells can initiate transverse defects, which ultimately cause broken rails.

The current rail standards include increased rail hardness and improved rail steel cleanliness, with the pearlitic steels peaking at 390 BHN. Recent research has focused on other structures such as bainitic steels. Although bainitic steels of the same hardness as pearlitic steel are not as wear resistant, high-hardness low-carbon bainitic steel offers wear resistance superior to pearlitic steel

As a guideline for transit installations the recommendation is to install clean rail steel with a hardness of:

- 300-320 BHN (standard rail) in tangent tracks, except at station stops and severe profile grades greater than 4%.
- 380-390 BHN in tangent tracks at station stops, severe profile grades greater than 4% , curved track with radii less than 500 meters (1,640 feet), and all special trackwork components including switch points, stock rails, guard rails, frog rails and rails within the special trackwork area.

These hardnesses may prove to be difficult to obtain in European girder rail sections. As a guideline, the girder groove rail should have a hardness of 300 BHN and greater.

5.2.2.3 Precurving of Tee Rail

Where the track radius is sharp enough to exceed the elastic limit of the rail, the rail must be precurved. These are the general guidelines for precurving tee rail:

- Standard Rail
  - Precurve rail horizontally for curve radius below 120 meters (400 feet).
  - Precurve rail vertically for curve radius below 300 meters (984 feet).
- High-Strength Rail
  - Precurve rail horizontally for curve radius below 100 meters (325 feet).
  - Precurve rail vertically for curve radius below 230 meters (755 feet).

Precurved rails are often in high wear locations where the rail is replaced more frequently. These locations often have standard joints rather than CWR to facilitate maintenance.

5.2.2.4 Procurement of Rail

Procurement of rail should be in accordance with AREMA Standard Specification Chapter 4, Part 2, Section 2.1, which includes specifics pertaining to transit agency requirements.

There is no standard rail or girder rail section for embedded track. The 115 RE rail section has been used for embedded track, with the bolted Pittsburgh strap-guard, with formed flangeways in either asphalt or concrete, or with the forming of a flangeway in the street. All of these have been used by various light rail transit systems. The ideal rail section for embedded track would be girder groove rail, with girder guard rail for the curved sections and more pronounced sharper radius curves.

5.2.3 Girder Groove Rail, "Rillenschiene", and Girder Guard Rail

The most commonly used running rail in embedded track (if tee rail is not used) is girder groove rail for tangent track and girder guard rail for curved track. The selection of girder groove rail currently available is limited to the European standards: Ri59N, Ri60N Ri52N, Ri53N, NP4a, and 35G as shown in **Figures 5.2.2** and **5.2.3**. To use these narrow flange girder rails, the wheel gauge and track gauge must be compatible with a reduced gauge clearance between wheel and rail to allow for wheel passage. The wheel flange profile may also be specialized, conforming to a transit wheel profile in lieu of the Association of American Railway (AAR) AAR-1B wheel profile. For additional information on wheel profiles and girder rail, refer to Chapter 2.

5.2.3.1 Girder Rail Sections

Grooved rail is known as "Rillenschiene" in Germany. Current popular German grooved rail sections are Ri59N and Ri60N. The rail identification Ri59N refers to:

- Ri: Rillenschiene for groove rail
- 59: mass (weight) 58.96 kilograms per meter (118.6 pounds per yard)
- N (or -13): 13-millimeter (0.51-inch) gauge corner radius

A recent revision to the Ri59 and Ri60 girder rails has been to change the radius of the rail head gauge corner from 10 to 13 millimeters (0.39 to 0.51 inches) and introduce the head configuration as a 1:40 cant position when the rail base is level. This rail section has been designated Ri59N or Ri59-13. Ri60N rail also has a 13-millimeter (0.51-inch) gauge corner radius. These modified rail head sections match the 115 RE rail head section. The latest development by an Austrian rail manufacturer is the rolling of the Ri60N girder groove rail with a 4-millimeter (0.16-inch) raised lip section to provide additional girder guard lip protection.

The new Ri girder rail head profiles match the 115 RE tee rail section. Wheel compatibility based on head radii and wheel contact zone is possible if the wheel profile is designed to suit both tee rail and girder rail sections. The wheel designer and the track designer must consider the impacts of wheel/rail performance resulting from standardized rail sections. For additional information on wheel/rail conformance refer to Chapter 2.

5.2.3.2 Rail Strength - Girder Rail

The customary European steel manufacturing practice is to roll standard rail sections in accordance with current UIC-860 V standards. The standard girder rails are produced with relatively soft rail steel in the normal grade, with a tensile strength (TS) of 685 Newtons per square millimeter (N/mm^2) as shown in **Table 5.1**.

- European steel manufacturers also roll rail sections in a wear-resistant grade with a minimum TS of 885 N/mm^2. This grade of

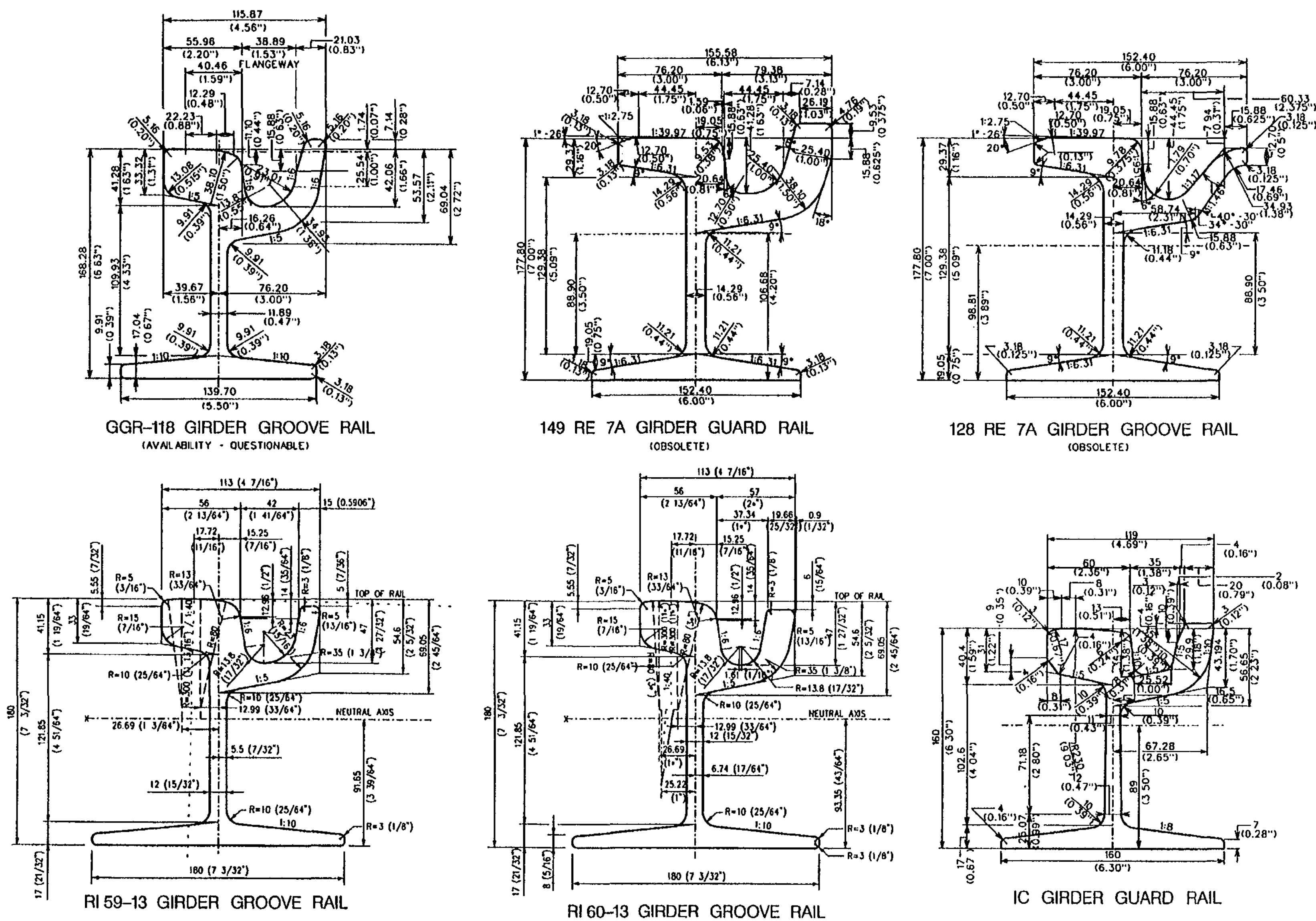
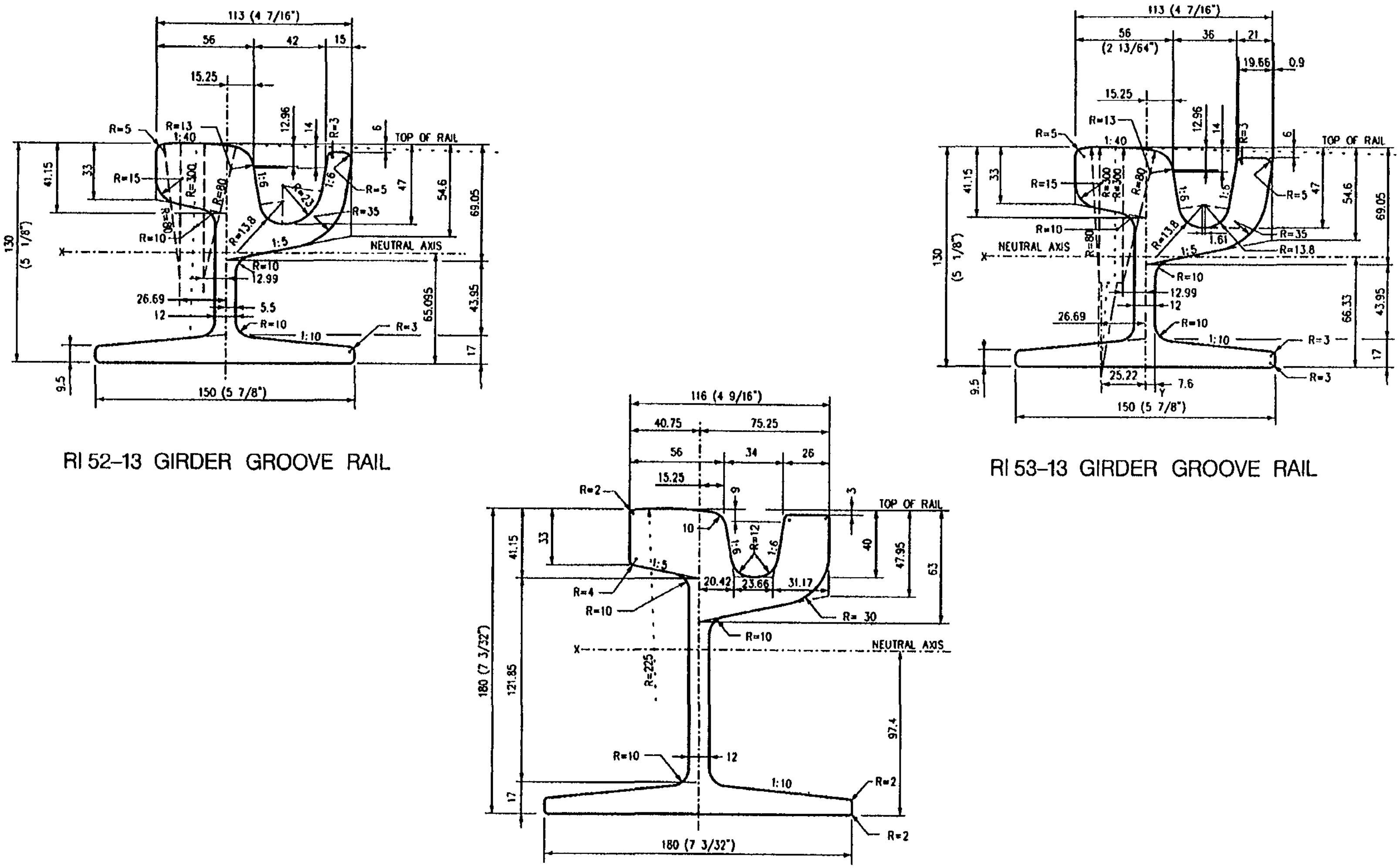


Figure 5.2.2 Typical Rail Sections—Girder Groove and Guard Rail Sections



RI 52-13 GIRDER GROOVE RAIL

RI 53-13 GIRDER GROOVE RAIL

NP 4a GIRDER GROOVE RAIL

Figure 5.2.3 Typical Rail Sections—Girder Groove and Guard Rail Sections standard steel is available in three classes: A, B, and C, where:

- C = Class is the wear-resistant
- B = Class is the primary class for girder rails, which provides a hardness of approximately 266 BHN
- A = Class rail is a very soft steel

A girder rail section to meet North American BHN standards requires a tensile strength of 1,080 N/mm^2 which equates to approximately 320 to 340 BHN according to **Table 5.2**.

Recent investigations with European steel manufacturers have indicated that girder rail in this class can be made available in alloy steel girder rail.

An alternative to the alloy steel is to use the standard European girder rail steel and provide wear resistance treatments consisting of wear-resistant weld inserts at the gauge corner, top of rail, and/or girder rail lip (see Section 5.2.5).

5.2.3.3 Precurving of Girder Rail

Like tee rail, girder rail must be precurved if the curve radius is sharp enough to exceed the elastic limit in the base or guarding face. The guideline for precurving girder rails:

- Horizontal: precurve girder rail for curve radii below 200 meters (650 feet).
- Vertical: precurve girder rail for vertical curve radii below 300 meters (984 feet).

Horizontal bending of girder rail will require vertical bending to obtain proper configuration due to the asymmetrical shape of the rail. These operations are best performed in roller straighteners at the mill.

Table 5.1
Chemical Composition of the Steels used for European Girder Rails

		Content In % By Weight					
		C (1)	Si	Mn	P	S	Cr
Normal grade with minimum TS of 685 N/mm^2		0.40/0.60	=0.35	0.80/1.20	=0.05	= 0.05	
Grade with minimum TS of 785 N/mm^2		0.45/0.63	= 0.5	0.80/1.30	=0.05	= 0.05	
Wear-resistant grade with minimum T.S. of 885 N/mm^2	A	0.60/ 0.75	= 0.5	0.80/1.30	=0.05	= 0.05	
	B	0.50/0.70	= 0.5	1.30/1.70	=0.05	= 0.05	
	C	0.45/0.65	= 0.4	1.70/2.10	=0.03	=0.03	
Chrome - manganese special grade steel with minimum TS of 1080 N/mm^2		0.65/0.80	= 0.8	0.80/1.30	=0.03	= 0.03	0.80/1.30

(1) C = Carbon
Si = Silicon
Mn = Maganese
P = Phosphorus
S = Sulfur
Cr = Chromium

Table 5.2
Relationship of Brinell and Rockwell Hardness Numbers to Tensile Strength

	Brinell Hardness Number		Rockwell Hardness Number		Rockwell Superficial Hardness Number, Superficial Diamond Penetrator			
Brinell Indentation Diameter (mm)	Standard Ball	Tungsten Carbide Ball	B Scale	C Scale	15-N Scale	30-N Scale	45-N Scale	Tensile Strength (Mpa) (N/mm^2)
2.50		601		57 3	89.0	75 1	63 5	2262
2.60		555		54 7	87 8	72 7	60.6	2055
2 70		514		52.1	86 5	70 3	47 6	1890
2 80		477		49.5	85 3	68 2	54 5	1738
2.90		444		47.1	84 0	65.8	51.5	1586
3.00	416	415		44 5	82.8	63.5	48.4	1462
3 10	388	388		41 8	81.4	61 1	45 3	1331
3 20	363	363		39.1	80 0	58 7	42.0	1220
3 30	341	341		36.6	78.6	56 4	39.1	1131
3 40	321	321		34.3	77.3	54 3	36 4	1055
3.50	302	302		32.1	76 1	52 2	33.8	1007
3 60	285	285		29.9	75 0	50 3	31.2	952
3 70	269	269		27.6	73 7	48.3	28 5	897
3.80	255	255		25 4	72.5	46.2	26 0	855
3.90	241	241	100.0	22.8	70 9	43 9	22 8	800
4.00	229	229	98.2	20.5	69 7	41 9	20.1	766
4.10	217	217	96 4					710
4.20	207	207	94.6					682

5.2.3.4 Procurement of Girder Rail

Procurement of girder rail by North American transit agencies requires a special contract specification stating the specifics as to rail section, strength, special treatments and potential precurving requirements in specific lengths of rail. The use of European standard UIC 860 V as a reference is acceptable, as long as additional special provisions are included.

As a guideline, the special provisions for procurement of girder rail should include: the ultimate tensile strength of the rail in particular the Brinell Hardness Number at the wearing surfaces, the compatibility of welding, precurving requirements, specific length of rails, and the method of corrosive protection during shipping.

5.2.4 Rail Wear

Rail has continually suffered from abrasive wear due to the steel wheel running on and against it. Surface head wear is due to the constant running of the wheels and is further compounded by the additional forces generated by braking and traction during deceleration and acceleration, respectively. In curved track there is added surface wear, where wheel slippage and load transfers occur due to superelevation and changing direction of the vehicle truck. Gauge face rail wear occurs due to the steering function of the rail. Steering contact is at the outer rail of a curve, which guides the outside wheel of the lead axle The action commences when the vehicle wheels negotiate the outside rail of the curve to the point where the wheel flange makes contact with the side of the rail head. This contact is referred to and measured as the "angle of attack." [4]

This attack on the outer rail is not caused by the vehicle's centrifugal force, but by the constant change in the vehicle's direction. The outer rail constantly steers the outer leading wheel inwards towards the curve center.

The wheel acts as a cutting edge, or grinding stone, that actually machines the gauge corner and face of the running rail. This is caused by several factors, such as the severity of the wheel's angle of attack to the rail, the stiffness of the vehicle truck which retards the curving action, and the velocity of the vehicle.

Another rail wear phenomenom is the formation of metal flow. The wheel/rail interaction causes the rail and steel surfaces to deform at the point of contact due to the concentrated load. This contact pressure is extreme to the point where the stress is greater than the yield point of the rail steel, which causes plastic deformation of the surrounding steel. This action leads to metal flow accumulation on the surface edges of the rail head. Metal flow collects at the gauge corner of rail in tangent track, where the wheel is seldom in contact with the rail gauge corner or face. This also occurs on the field side of the inside rail of curves, where the rail head metal flow migrates toward the field side and accumulates as a pronounced lip.

Corrugation of rail is another rail wear phenomenom that impacts ride quality and noise generation. Corrugation is discussed in Chapter 9, *Noise and Vibration Control.*

5.2.5 Wear-Resistant Rail

Transit systems have historically suffered from worn rails and the need for premature rail replacement due to accumulative wear limits of the rail head and/or gauge face. To combat the wheel machining of the rail gauge face and loss of metal, an abrasion-resistant steel is required. Improvements in the chemical composition and treating process of rail steel have led to the development of wear-resistant types of steel. Research has shown that pearlitic steel with sufficient hardness retards the wear and abrasion (or machining) of steel and the formation of corrugation. [5]

The hardness of rail steel is proportional to its toughness or its ultimate tensile strength (UTS). UTS is used to measure the quality of the steel.

As stated earlier, rail producers in Europe are not accustomed to supplying non-alloy special groove rail and other rail sections in the range of 1,100 UTS (320 to 340 HBN). To overcome this deficiency in the rail, a special welding procedure has been used to provide a wear-resistant surface to the rail. The special welding known as Riflex[6] also features anti-squeal characteristics.

5.2.5.1 Riflex Welding

The Riflex welding procedure includes three types of rail welding as follows:

- Riflex—corrugation reduction or elimination and head wear reduction
- Eteka 5—rail gauge corner and face wear reduction
- Riflex AQ—anti-screech weld material developed to control noise

The Riflex process includes four steps:

1. A groove is machine cut into the ball or the gauge face of the rail.
2. Using submerged arc welding techniques, an alloy is welded into the groove.
3. The rail is ground smooth.
4. The rail is roller straightened and ultrasonically inspected. Riflex welding can also be field applied with rail in place.

The three types of weld materials used in the Riflex process have different hardnesses. The Riflex anti-corrugating material is applied in a very hard state—approximately 600 BHN—and develops a final hardness of about 700 BHN. The Eteka 5 material is applied to the rail in a fairly soft form, but develops a hardness of 550 to 600 BHN very quickly.

The AQ anti-screech material is applied in a soft state and develops a hardness of about 80 BHN. Although the AQ material is soft, it is protected by and designed to wear at the same rate as the surrounding rail. Additional information on Riflex welding is included in Chapter 9.

Riflex welding applications have had mixed success in North America. The carbon content of rail specified in North America has resulted from adverse performance in the welding procedure and long-term performance. The use of the Riflex process requires a detailed specification procedure that matches the rail steel.

5.3 RESTRAINING RAIL DESIGNS FOR GUARDED TRACK

Guarded track in light rail transit design, as described in Chapter 4, reduces curve wear on sharp curves by restraining the wheels away from the outer rail. The guard (or restraining) rail is close to the inside rail of the curve and contacts the back of the inside wheel flange. The design of guarded or restraining rail differs, and over the years various designs have been used. Traditionally, curve guarding on street railway systems was frequently achieved using a girder guard rail section similar to the rail sections illustrated in Figure 5.2.2. Ballasted and direct fixation track requiring guarding used a separate restraining rail mounted adjacent to the running rail. Exceptions can be found, depending on the requirements and circumstances of a particular system.

The following sections discuss the various designs for guarded track or restraining rail. Sharp curves with restraining rail are very complicated to fabricate and construct in the field. Prefabricating curves on a shop floor can improve quality and reduce field installation time.

5.3.1 Girder Guard Rail for Embedded Track

Many historic North American girder guard rail sections were either 140ER7B or 152ER9B and, more recently, 149 RE7A. These sections were developed specifically for embedded street track to provide a substantial restraining rail guard lip or tram on the rail to act as the restraining guard face. In tangent track a mating girder groove rail section of similar height with a reduced girder rail lip was available to complete the embedded track installation.

These girder groove rail and girder guard rail sections were developed to suit specific wheel profile sections and transit wheel gauge resulting in a reduced flangeway. The last section rolled in North America, the 149 RE-7A, was a railroad girder guard rail with a wider flangeway that was compatible to the AAR wheel and wheel gauge. Earlier contemporary light rail systems adopted this girder guard rail section as standard to suit the AAR vehicle wheel gauge. These sections are no longer manufactured or rolled.

To fill the availability void in girder groove and girder guard rail, European girder groove rail sections have been used. The most popular European sections are Ri59, Ri60, and GGR-118. These sections are all pure transit girder rail sections with reduced flangeway widths as shown on Figure 5.2.2. The GGR-118 girder groove rail section is no longer available. Other girder groove rail sections rolled in Europe that can be considered for transit use in North America are the IC, Ri52N, Ri53N, NP4a, and G35. European girder rails are not compatible with freight operations. Recently the Ri60 girder groove rail was modified to increase the girder lip height to introduce a section conforming to girder guard rail requirements.

The dilemma confronting the North American light rail track designers is the lack of a suitable girder guard rail section with the increased flangeway width required to provide guarded track in embedded sharp radius curved track sections. The European girder groove rail sections are adaptable if a transit wheel gauge is selected for the wheel set. The AAR wheel gauge of 1414 millimeters (55.6875 inches) is not compatible with these girder rail sections.

Alternate design methods have been used in embedded track to overcome the flangeway width issue. These designs included the "Pittsburgh" strap guard with 115 RE rail, the use of conventional tee rail restraining rail, and the use of 115 RE rail with a formed flangeway with no restraining rail protection. Unfortunately, none of these design concepts provides the ultimate rail section, and they have proven to be adequate at best.

As a guideline, a transit wheel profile and transit wheel gauge of 1421 millimeters (55.94 inches) are recommended and the modified Ri 59N girder groove rail section with a hardened girder tram lip can be used in sharp radius curved track. This combination of transit-related standards provides an adequate guarded track system. A wider wheel gauge of 1429 millimeters (56.25 inches) would allow the use of Ri60N girder groove rail with the proper truck wheel set (axle spacing).

5.3.2 Tee Rail for Guarded Ballasted and Direct Fixation Track

Ballasted and direct fixation track with sharp curves have used various designs to provide the required restraint. Guarding is typically provided by mounting a separate "restraining rail" parallel and concentric to the inside running rail, with the horizontal distance between the two rails set at the required flangeway dimension.

The restraining rail can be fabricated from one of several steel shapes and may or may not be physically attached to the running rail. In versions that are physically bolted to the running rail, the restraining rail/running rail assembly must be designed as a unit so that curvature is consistent and bolt holes in both rails are aligned.

5.3.2.1 Vertically Mounted Restraining Rails

The most common type of restraining rail is a vertically mounted tee rail as shown in **Figure 5.3.1**. The restraining rail is fabricated by planing away a portion of the base of a standard tee rail, which is then bolted to the running rail at intervals of 600 to 900 millimeters (24 to 36 inches). Cast or machined steel spacer blocks are placed between the running rail and the restraining rail to provide the desired flangeway. Some designs fabricate the spacer blocks in two pieces and insert shims between them to adjust the flangeway width so that the flangeway can be restored to the design dimension as the guard rail face wears. Although this design feature appears sound, few transit systems actually take advantage of this maintenance feature.

The restraining rail and the running rail webs must be drilled to insert connecting bolts. The bolt hole spacing must be detailed on the shop drawings because the restraining rail is on a slightly larger horizontal radius than the running rail to which it is attached. In addition, the bolt hole spacing will be different on each rail. While this differential is minor between any pair of bolt holes, it will become significant when accumulated over the full length of a rail.

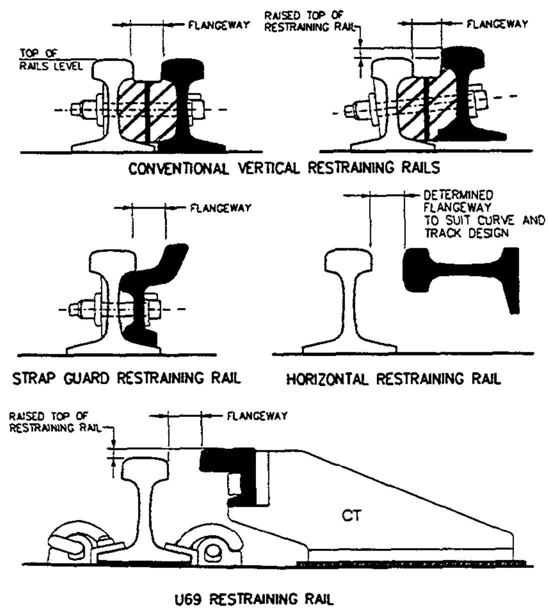


Figure 5.3.1 Typical Restraining (Guard) Rail Arrangements

For curves with radii less than 100 meters (328 feet), combined running and restraining rails are typically precurved and fabricated together on a shop floor. For ease of shipment, these precurved segments are usually 12 meters (39 feet) long or less. For curves with radii greater than 100 meters as well as through curve spirals, where the running rail can usually be field sprung (bent) to the desired curve, shop curving of both running and restraining rails is typically not performed. To eliminate the need to drill countless holes in the field conditions, only the restraining rail is drilled. The restraining rail is often the same rail section as the running rail. In cases where the restraining rail is elevated above the head of the running rail, the restraining rail is fabricated from the next larger rail section (e.g., 115 RE running rail would be paired with a 132 RE restraining rail). In other designs, the same rail section is used, but a riser shim is welded to the rail fastening plate beneath the restraining rail to elevate it.

If elastic rail fastenings are used, the spacing between the restraining rail bolts and the crosstie or rail fastener should be coordinated to ensure that the bolt assembly will not interfere with insertion of the elastic rail clip. The bolt must be able to be tightened without requiring removal of the rail clip.

The combined running rail/restraining rail assembly will usually be installed on a common extended rail fastener or tie plate unlike those used under single running rails. Restraining rail installed on concrete crossties will require a special restraining rail crosstie with a wider shoulder mounting.

Vertically mounted restraining rails have been used in all the types of track structures. When employed in embedded track, it is necessary to seal the flangeway to keep out moisture and debris. A restraining rail assembly in embedded track will have multiple paths for seepage. Even with sealants, it is critical to provide sub-drainage to keep the track dry.

5.3.2.2 Horizontally Mounted Restraining Rails

Transit systems have used horizontal designs where the restraining rail is mounted with the rail's Y axis oriented horizontally, as shown on Figure 5.3.1. This is a relatively old design that is currently used only in older transit installations.

As a guideline, horizontally mounted restraining rail is not recommended for light rail transit use although some traditional streetcar systems used it at one time. Horizontally mounted restraining rail cannot be used in embedded track areas.

5.3.2.3 Strap Guard Rail

A relatively recent restraining rail design uses a special rolled section, known as the Pittsburgh strap guard, with 115 RE rail as shown in Figure 5.3.1. The strap guard section can be bolted directly to the web area of the running rail. The strap guard section was developed for the Pittsburgh light rail transit system in the early 1980s based on similar sections that were rolled for ASCE rails in the early 20th century. This section, as presently designed, accommodates only small streetcar-sized wheel flanges. Where it was used with railroad wheel flanges, it was necessary to insert shims between the web of the running rail and the strap guard to obtain a wider flangeway.

One advantage of the strap guard rail is that it does not require special rail fasteners or crossties. The only requirement is a specially designed rail clip that can bear on the lower flange of the guard on the gauge side of the assembly. The field-side rail holddown device can be the same as that used in single rail installations, which facilitates adding strap guards to an existing curve that is experiencing rail wear.

The main disadvantage of the strap guard is that a large number of holes must be drilled in both the strap guard and the running rail and a large number of threaded fastenings must be maintained.

As a guideline, the strap guard rail assembly should be used only as a last resort for either girder rail or girder guard rail light rail transit installations.

5.3.2.4 UIC33 (U69) Restraining Rail

A new restraining rail design for use in North American light rail transit system is the popular UIC33 section from Europe. The UIC 33 section is also referred to as the U69 or RL-160 section. For standardization, hereinafter the section will be referred to as the U69 restraining rail section. The U69 section in Europe has primarily been used as a guardrail for special trackwork frog locations. The U69 section has also been used for frog guardrails on several North American light rail transit systems.

The major advantage of using the U69 section as a restraining rail is the capability of independent mounting from the running rail as shown in Figure 5.3.1. To improve on its function as a restraining rail, the U69 section features a raised design The restraining rail face is positioned 20 millimeters (0.7887 inches) above the top of the running rail, to allow additional contact with the flat vertical face of the back of wheel.

The independent mounting is provided by a mounting bracket that allows the restraining rail to be mounted adjacent to the running rail, providing the required flangeway width. The mounting bracket design can either be separate from the running rail fastening plate, direct fixation fastener, or an integral part of the fastening plate.

5.3.3 Restraining Rail Recommendations

As a guideline the following mountings are recommended:

- Concrete Crosstie Track—a separate U69 mounting is provided by two additional anchor bolt inserts that are cast in the concrete crosstie during tie production. The installation should be insulated and the bracket designed to clear the running rail fastening.
- Direct Fixation Track—a separate U69 mounting is provided by two additional anchor bolt inserts cast in the direct fixation concrete plinth during plinth installation. The installation should be insulated and the bracket designed to clear the direct fixation fastener components.
- Timber Crosstie Track—joint U69 mounting with the running rail fastening plate. A welded assembly or cast steel

fastening plate can be used. The single unit fastening plate with a bracket provides improved holding by using the weight of the vehicle to retain the plate bracket position. The installation should be insulated, and the bracket designed to clear the running rail fastenings.

The U69 restraining rail assembly provides for flangeway width adjustment by adding shims directly behind the U69 restraining rail. This adjustment can be undertaken without disturbing the running rail installation.

The U69 restraining rail can be provided in 15- and 18-meter (49- and 59-foot) lengths. Special four bolt joint bar assemblies are used to join these lengths. To allow for minor thermal expansion in the U69 section, it is recommended that slotted holes be made in the joint bars.

On aerial structure installations where thermal expansion of the structure must be accommodated, the U69 restraining rail mounting bolt holes at each mounting bracket should be slotted to allow the structure to move longitudinally.

On sharp radius curved track installations, the precurving of the U69 section is preferred in lieu of springing (bending) the U69 restraining rail into position. Design and shop drawing layout of the curved track to conform to the various installations is required.

5.3.4 Restraining Rail Thermal Expansion and Contraction

Restraining rails undergo thermal adjustment as do running rails. They should not be continuously welded because it would be virtually impossible to install them at the same zero thermal stress temperature as the adjacent running rails. It is customary, therefore, to fabricate restraining rail in 9- and 12-meter (30- and 39-foot)-long segments and provide expansion gaps at bolted restraining rail joints. If the adjoining running rail is continuously welded, any connections between the restraining rail and the running rails should allow for some longitudinal movement between the two rails. This can be accomplished by drilling oversized bolt holes.

5.4 FASTENINGS AND FASTENERS

The fastening is the device that holds the rail in place on either a tie plate, direct fixation fastener, or concrete crosstie. While the original spike was used to provide lateral support, new elastic fasteners also restrain longitudinal forces in CWR.

Track designers are continuously striving to improve rail fastenings and fasteners. Current popular fastenings include:

- Conventional rolled tie plates with cut spikes, used on timber ties (no insulation).
- Rolled formed shoulder tie plates with elastic rail fastenings and cut or screw plate holddown spikes, used on timber ties (with or without insulation).
- Plates with rigid crane rail clips, used in embedded and direct fixation track.
- Insulated elastomer direct fixation fasteners used on direct fixation track and occasionally in embedded track.

5.4.1 Insulated Fastenings and Fasteners

The light rail vehicle draws power from the overhead catenary wire and returns it through the running rails to the power substation. The use of the running rails as an electrical conductor is one of the main differences between freight railroads and light rail transit systems. The negative return current must be controlled at the rail to retard or reduce stray current leakage, which causes corrosion of transit track structures, utilities, and nearby structures. For additional information on stray current protection refer to Chapter 8.

The rail fasteners and fastenings are used to insulate the rail from the ground Ballasted track often relies on timber ties to insulate rails from the ground. Although wood is considered a non-conducting material, the timber crosstie does not provide total insulation for the negative return running rail. Additional insulation may be provided to further isolate the rail and/or fastening plate from the timber crossties where stray current corrosion is an issue.

On concrete and steel ties, elastic clip fastenings are used. The clips are insulated from the rail by plastic insulators and the rail is placed on an insulating pad. Insulated track fastenings or fasteners are needed to attach rails in ballasted, direct fixation and embedded track. However, track fastenings may be omitted in embedded track designs where the rails are supported by embedment materials.

5.4.1.1 Isolation at the Rail Base

To provide electrical isolation of the rail from the surrounding track components, the insulating barrier must be installed at the base of the rail or mounting surface. The insulating barrier consists of a rail base pad and insulators for the edges of the rail base. The rail base may be fully insulated from the mounting surface, as shown in **Figure 5.4.1**.

5.4.1.2 Isolation at the Fastening or Fastener Base

To provide electrical isolation of the fastening from the surrounding track components, the insulating barrier must be installed at the base of fastening or mounting surface. The insulating barrier consists of an insulated base

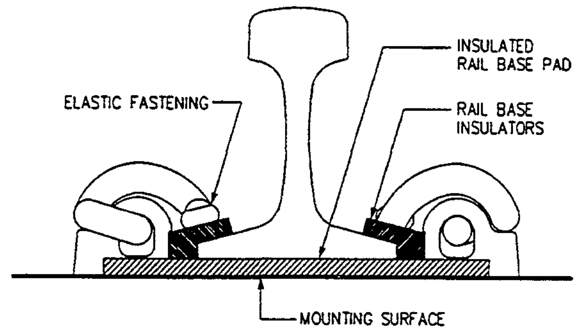


Figure 5.4.1 Isolation at the Rail Base

fastening pad and insulating thimble-collars for the anchoring screws or bolts, as shown in **Figure 5.4.2**.

5.4.2 Fastenings for Timber and Concrete Crossties for Ballasted Track

The current standard for light rail transit ballasted track is to use either timber or concrete crossties. For additional information on ballasted track refer to Chapter 4.

Traditionally, track constructed with timber crossties, CWR, and cut spikes also included rail anchors to restrain the rail from movement. This style of track installation has been economically replaced with elastic spring clips to hold the rail to the tie plate. The elastic clip now provides the longitudinal restraint as well as holding the rail down. These clips eliminate rail anchors that protrude into the ballast and are virtually impossible to insulate to provide stray current protection.

The trend in design of main line LRT track appears to be toward the use of concrete crossties. Concrete crossties provide superior gauge, line, and surface retention over timber crossties and the simple fastening method of elastic clips holds the rails and electrically isolates them from the ground as shown in Figure 5.4.1. Main line transit track with

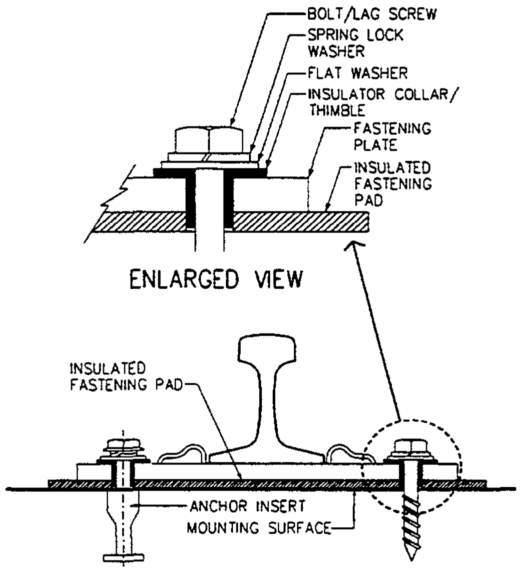


Figure 5.4.2 Isolation at the Fastening or Fastener Base

timber crossties must consider the insulation method shown in Figure 5.4.2 with screw spikes used to secure the tie plate. Economically, concrete and timber crossties with insulated tie plates are approximately equal in cost for large-volume procurements. This may change depending on the availability of timber.

Special trackwork installations on timber and concrete switch ties must consider the insulating method shown in Figure 5.4.2. This is similar to main line timber crosstie installations, which use larger special trackwork fastening plates at the switch and frog areas. Insulated plates, screwed to the timber or concrete crosstie insert with an elastic spring clip for rail support, have a proven service record.

5.4.3 Fasteners for Direct Fixation Track

Direct fixation track is most often constructed on:

- Concrete slab track at-grade
- Concrete invert in tunnels
- Concrete deck on aerial structures

For additional information on direct fixation track design, refer to Chapter 4.

Although rails can be attached to concrete decks as shown in Figure 5.4.1, the common practice in direct fixation track is to use a bonded (or unbonded) direct fixation (DF) fastener plate as shown in Figure 5.4.2.

The terms fastening and direct fixation fastener refer to two distinct track components. Fastenings are the individual components, or series of components, mounted separately to hold the rail tight in place, such as on a concrete crosstie with no plate. Direct fixation fasteners consist of a vulcanized/bonded steel plate and elastomer pad or a steel plate mounted on an unbonded elastomer pad. The direct fixation fastener plate often provides lateral rail adjustment in the anchor bolt area.

All modern heavy rail transit systems, starting with Toronto in 1954 and BART in 1968, have used resilient DF fasteners in subway track and aerial track. DF fasteners have been redesigned and improved to the point where there are numerous styles from which to choose.

One of the earliest DF fastener designs is the Toronto Transit Commission's (TTC) unbonded fastener with a natural rubber pad. Later designs included vulcanize bonded fasteners with rolled steel top and bottom plates. More recently, fasteners with either rolled steel, cast top plates, or cast bases are being used. Fasteners with a soft elastomer material are available to provide an extra measure of groundborne noise reduction.

DF fastener designs have used various fastenings including bolted rail connections, rigid clips and spring wedges, and elastic spring clips with variable toe loads. The elastomer pad has been manufactured with synthetic elastomers, natural rubber elastomers, and polyurethane materials. These materials have been formulated to provide both high- and low-spring rates for the track. Fasteners are held to the invert with anchor bolts consisting of embedded studs with spring washers and nuts or female anchor inserts with spring washers and bolts. Some of the earlier designs were inadequate because of problems in design, material, installation, or overloading.

Resilient DF fasteners have long been used by U.S. transit systems. These fasteners provide a moderate degree of vibration isolation, require less maintenance, and produce better rail alignment than ballasted track. The typical static stiffness of DF fasteners used by various U.S. systems is on the order of 20 to 50 MN/m (112,000 to 280,000 pounds per inch), with spacing ranging from about 760 to 900 millimeters (2.5 to 3 feet). Recent concerns over the control of rail corrugation and the desirability of approximating the stiffness of ballast and crosstie track have modified the design of DF fasteners such that the stiffness is on the order of 19 MN/m (106,000 pounds per inch). These fasteners incorporate elastomer bonded between a cast iron or steel top plate and stamped steel base. A snubber is installed between the top and bottom plates, beneath the rail seat, to limit lateral motion of the top plate. Lateral rail head stiffness is on the order of 5 MN/m (30,000 pounds per inch). Fasteners have been supplied with vertical stiffness on the order of 20 MN/m, but with very low lateral stiffness on the order of 1.75 MN/m (9,800 pounds per inch), due to lack of a snubber or other lateral restraint. These differences in lateral stiffness reflect differences in design philosophy.

Fastener designs that control structure-radiated noise often feature an anchoring system with anchor bolts that directly attach the base plate to the concrete invert or crosstie, without passing through the top plate. This approach eliminates lateral bending moments, which would otherwise be applied to the anchor bolts due to lateral rail forces

5.4.3.1 Fastener Design Consideration

The principal design parameters for direct fixation fasteners are discussed in the following paragraphs:

5.4.3.1.1 Vertical Static Stiffness

Vertical static stiffness is often called spring rate, and represents the slope of the load versus deflection over a prescribed range of 5,000 to 55,000 N (1,000 to 12,000 pounds). Current light rail track designs include a static stiffness of about 18 to 21 MN/m (100,000 to 120,000 pounds per inch), which, with a 760-millimeter (30-inch) fastener spacing, gives a rail support modulus of about 26 MN/m^2 (3,700 pounds per square inch). One feature of low stiffness fasteners is that they distribute rail static deflection over a larger number of fasteners, making the rail appear more uniformly supported. Low rail support stiffness reduces the pinned-pinned mode resonance frequency due to discrete rail supports, as well as the rail-on-fastener vertical resonance frequency. Static stiffness in the 18 to 21 NM/m range provides reasonable control of track deflection in the vertical direction without unduly compromising lateral stiffness.

5.4.3.1.2 Ratio of Dynamic to Static Stiffness (Vertical)

The ratio of vertical dynamic to static stiffness is a very important quantity that describes the quality of the elastomer. A low ratio is desirable to maintain a high degree of vibration isolation. A desirable upper limit on the ratio is 1.4, which is easily obtained with fasteners manufactured with a natural rubber elastomer or a rubber derivative. Ratios of 1.3 are not uncommon with natural rubber elastomer in shear designs. As a rule, elastomers capable of meeting the limit of 1.4 must be of high quality and generally exhibit low creep.

5.4.3.1.3 Lateral Restraint

Lateral restraint is the ability of the fastener to horizontally restrain the rail. High lateral restraint is often incompatible with vibration isolation design requirements. Therefore, fasteners that provide adequate stiffness to guarantee both an adequate degree of horizontal position control as well as vibration isolation are desirable. Snubbers are protruding portions of metal plate that penetrate the adjoining plate to act as a limit flange in controlling lateral displacement. The guiding design principle is to provide a three degree-of-freedom isolator. Hard snubbers are undesirable in fasteners, because they limit vibration isolation only in the vertical direction.

5.4.3.1.4 Lateral Stiffness at the Rail Head

Lateral stiffness is measured at the rail head and includes the effect of fastener top-plate rotation. Light rail track design must maintain rail head position within tight tolerances on both curves and tangent track. This is potentially in conflict with the requirement for horizontal vibration isolation. The lateral deflection of the top plate of typical sandwich fasteners is limited by the snubbers and to a lesser extent by the elastomer in shear. If the snubber is located beneath the rail, a low fastener with low vertical stiffness will have low rotational stiffness and thus poor rail head control. This conflict has been overcome by one European design, which incorporates elastomer in shear with a large lateral dimension to resist overturning. Another way of overcoming this potential conflict is to move most of the elastomer to the ends of the fastener, away from the rail center, thus maximizing the reaction moment to overturning forces. A snubber should not be installed at the center of the fastener. If a snubber is required, it should be located towards the lateral ends of the fastener to minimize rotation of the rail by forcing the rail to rotate about a point located towards the field side of the rail in response to gauge face forces.

5.5 CROSSTIES AND SWITCH TIES

Ballasted track requires crossties to support the rail. Chapter 4 discusses crossties in the design of ballasted track. Crossties are used mainly for ballasted track, although they are occasionally used in both direct fixation encased track, where a crosstie or sections thereof are encased in a concrete track structure, and in embedded track, where the crosstie is embedded with the track structure

Crossties are generally made of three specific materials: timber, concrete or steel. There has been some experimenting with composite crossties consisting of epoxy composites and plastics. These composite ties have seen little service and are not discussed further herein.

The development of pre-stressed precast concrete at reasonable prices has led to the current concrete crosstie design, which features encased rail shoulders and sundry inserts for the application of trackwork components. The concrete crosstie designs have been refined to suit light rail transit use. A recent innovation is the design of the serrated side (scalloped) concrete crossties that improve lateral stability.

Light rail transit systems use both timber and concrete crossties. The predominant standard appears to be concrete crossties for the main line track, with timber ties for maintenance facility and yard tracks. Special trackwork installations for both main line and yard track use timber ties, although concrete ties have been considered and recently implemented on a transit system.

5.5.1 Timber Crossties

The timber currently used in crossties includes selected hardwoods, with tropical species also being considered. The reduced availability of this timber has driven up the cost of ties, as has the environmental aspects of treating the wood. For new light rail transit systems constructed in early 1980s, timber ties (wood is a non-conductor) provided sufficient electrical isolation. Today, many believe that additional insulation is required in locations where stray current corrosion is an issue. Recent timber tie fastening designs include a tie plate that adds a layer of insulation between the bottom of the tie plate and the top of the tie.

The requirement for an insulated tie plate to be mounted on the timber tie dictates the general width of the tie. Standard tie plate widths range from 180 to 190 millimeters (7 to7-½ inches), with an insulated tie pad protruding a minimum of 12 millimeters (1/2 inch) on all sides of the tie plate results in a minimum width of 204 millimeters (8 inches). A 230-millimeter (9-inch) wide timber tie provides sufficient surface to support the total insulator pad with no overhang beyond the edge of tie. Skewed tie plates at special trackwork locations must consider the overhang issue in relation to degree of the skew angle.

The length of crosstie relates to the standard track gauge of 1435 millimeters (56-½ inches) and is generally 2590 millimeters (8 feet 6 inches) long. Transit systems with a wider track gauge require a longer timber crosstie.

Timber crossties are generally required to conform with the current specifications of the AREMA Manual, Chapter 30 (formerly 3) *Ties and Wood Preservation.*

As a guideline, timber crossties for light rail transit use should be hardwood—preferably oak—and generally 180 x 230 millimeters (7x9 inch) wide x 2.6 meters (8 feet, 6 inches) long. Tie length may vary depending on the track gauge selected. The 7-inch tie depth is referred to as a 7-inch grade crosstie. (The metric system has not been used to classify tie sizes).

When using timber crossties conforming to AREMA recommendations, the type of wood, tie size, anti-splitting device, wood preservative treatment, and machining should be specified in the procurement contract.

5.5.2 Concrete Crossties

Concrete crossties are becoming more common in light rail transit designs as life cycle costing makes them competitive with timber crossties. The most common concrete crosstie is the monoblock tie with embedded cast steel shoulders and pre-tensioned wires. The rail fastening system consists of an elastic clip with insulating rail seat pad and clip insulators, as shown in Figure 5.4.1.

In addition to the conventional crosstie that holds the two running rails, a special crosstie is needed to hold the restraining rail in guarded track at sharp curves. The size of the two ties is similar. The configuration of the restraining rail crosstie provides a relatively level surface between the rails to support the specific design of the restraining rail assembly.

The standard size of light rail transit concrete crossties is generally 255 millimeters (10 inches) wide and 2515 millimeters (99 inches) long at the base of tie. The tie is tapered to a 190-millimeter (7.5-inch) height at the rail seat and a 165-millimeter (6.5-inch) height at the center of the tie. The height at the center of the tie will increase to suit the restraining rail design. The length of concrete crossties may vary between transit systems; however, 2515 millimeters (8 feet 3 inches) appears to be the most common length for standard track gauge.

The concrete crosstie design for light rail transit track is based on the light rail vehicle weight, anticipated loads and vehicle operating velocity. It is generally a smaller version of the concrete railroad crosstie with less reinforcement and a reduced cross section sufficient to meet the positive and negative rail seat and tie center bending test requirements. Specifications for concrete crossties in light rail transit track differ from standard railroad track crosstie specifications due to the different vehicle loads and resultant forces on the crossties. The concrete railroad crosstie is a sturdier tie in conformance with the specifications of AREMA Manual, Chapter 30.

5.5.2.1 Concrete Crosstie Design

The design of concrete crossties for light rail transit track is based on performance specifications that consider:

- Tie spacing
- Tie size
- Wheel loads
- Impact factor

5.5.2.2 Concrete Crosstie Testing

Prior to acceptance of the concrete crosstie design, the manufactured crosstie should be tested for compliance with specifications and the determined calculated load limits. The tests should be conducted in accordance with the procedures outlined in the AREMA Manual, Chapter 30.

5.5.3 Switch Ties—Timber and Concrete

Special trackwork switch ties for light rail transit system installations have been primarily timber based on conventional railroad standards

Concrete switch ties have been developed by the railroad industry to meet heavy haul freight maintenance requirements. History has shown that high engineering design and fabrication costs contributed to the limited use of concrete switch tie sets, with timber being more economical.

The transit industry's minimal use of concrete switch ties has been primarily on commuter railroad lines utilizing large-size turnouts and high-speed turnouts.

Various turnout standards exist among light rail transit agencies; therefore various concrete tie geometric layouts and designs would be required to meet all requirements. Standardization and simplicity in tie design is required to provide the light rail transit industry with a uniform standard concrete switch tie set for the various turnout sizes.

5.5.3.1 Timber Switch Ties

Timber hardwood switch ties is the standard for light rail transit special trackwork turnouts and crossovers. In locations where stray current corrosion is an issue, added insulation is needed.

Similar to main line timber crossties, the requirement for an insulated switch tie plate to be mounted on the tie dictates the general width of the tie. A 230-millimeter (9-inch) wide timber switch tie provides adequate surface to support the entire insulator pad with no overhang beyond the edge of the tie. Special trackwork plates or fastenings are subjected to skewing of the plates to provide a perpendicular mounting at the rail base. Otherwise, special provisions within the plate design must allow the plate to mount parallel to, and entirely on, the tie surface. Skewed plates or insulation should not project beyond the edge of tie.

Timber switch ties should be supplied in accordance with current recommendations, of the AREMA Manual, Chapter 30.

As a guideline, timber switch ties for light rail transit use should be hardwood—preferably oak—and generally 180 x 230 millimeters (7 x 9 inches) wide and of a suitable length for the turnout installation. The switch tie sets generally conform to AREMA Standard Plan No. 912.

When using timber switch ties conforming to AREMA Manual recommendations, the type of wood, tie size, anti-splitting device, wood preservative treatment, and machining should be specified in the procurement contract.

5.5.3.2 Concrete Switch Ties

Current concrete switch tie designs have generally been a joint effort between the transit authorities and the concrete tie manufacturers through various technical committees. The turnout design provides the geometric layout establishing the tie spacing and the corresponding tie lengths. The spacing for concrete ties must deviate from AREMA standards for timber switch ties due to the increased width of the concrete switch tie. Threaded anchor inserts in the tie are a requirement for standard switch plates, frog plates and guard rail plates. Areas of the turnout layout where single rail installation is required, such as the closure curve zone between the heel of switch and toe of frog, will require an alternate rail mounting method.

The standard conventional embedded shoulder and elastic clip, with proper insulation, may be used at locations on the switch tie where clearance allows the four rails to be mounted individually. The height differentials between switch, frog and guard rail plates and the standard conventional rail installation must be considered in the design. Generally the single rail locations have a built-up concrete base to match the plated top of rail height.

Standards for concrete switch ties should be developed for various turnout and crossover arrangements in light rail transit track. Standardization will allow for more economical engineering and manufacturing and increased use of concrete switch ties, which are more compatible with concrete main line crossties.

As a guideline, concrete switch ties for light rail transit use should be approximately 255 millimeters (10 inches) wide at the top of tie, 285 millimeters (11.25 inches) wide at the base of the tie, and 240 millimeters (9.5 inches) high throughout. The length should be sufficient to suit the turnout geometry and provide sufficient shoulder length. The fastenings and switch, frog, guardrail, and turnout plates should be insulated to retard stray current leakage. The concrete switch ties should comply with the appropriate specifications for concrete ties, as outlined in AREMA Manual, Chapter 30.

5.6 TRACK (RAIL) JOINTS

Rail joints are the weakest component in the track structure, and are unavoidable on any track structure. To connect the short lengths of rolled rail, a rail joint is required. There are various types of rail joints grouped as follows:

1. Welded Joints
   - Pressure electric flash butt weld
   - Thermite (kit) weld
2. Insulated joints
   - Standard non glued bolted insulated joint
     - 4-Hole
     - 6-Hole
   - Glued Bolted Insulated joint
     - 4-Hole
     - 6-Hole
3. Bolted Joints
   - Standard (Non Glued) Bolted Joint
     - 4-Hole
     - 6-Hole
   - Glued Bolted Joint
     - 4-Hole
     - 6-Hole

5.6.1 Welded Joints

Welded rail joints forming continuous welded rail out of many short lengths of the rail has been standard in the railroad industry for over 40 years. Elimination of bolted rail joints has improved the track structure and reduced the excessive maintenance required at bolted rail joints. Rail welding in North America is generally accomplished using either the pressure electric flash butt weld or the thermite weld method. CWR strings allow the DC current to be carried efficiently through the rails.

5.6.1.1 Pressure Electric Flash Butt Weld

Most rail strings are welded together by the pressure welding process (flash butt welding) in a welding plant operation. The rolled rail sticks are welded continuously in various predetermined rail lengths capable of being transported to the track laying location by special rail trains. CWR lengths are nominally 439 meters (1440 feet). Rail strings used in light rail transit construction are often half this length to facilitate transport of the rail to the site.

Electric flash butt welding is defined as a forged weld where an electrical charge is passed between the rails until the steel is plastic. The rails are then forced together to the point at which the steel refuses further plastic deformation.

5.6.1.2 Thermite Weld

Thermite welds are produced with molten steel, cast from a crucible, and poured into the gap between two rails. The molten steel is produced with a chemical "exothermic" reaction between aluminum and iron oxides. Additives in the mix create the other components needed to make the steel. Thermite welding requires preheating the rail ends in order to create a good bond between the old and new steel. It is important that the resultant steel plug has the same hardness as the parent rail steel. Manufacturers can produce welds with different hardnesses to ensure compatibility.

CWR rail strings are generally joined or welded together by the thermite weld process.

Portable flash butt welding is an alternative to the thermite weld process. A flash butt welding head is transported to the installation site to join the CWR strings. Either weld method is acceptable.

Welding rail eliminates bolted joints and most of the associated joint maintenance. However, CWR creates other issues, such as structural interaction on bridges which must be addressed by the designer (refer to Chapter 7).

5.6.2 Insulated and Non-Insulated Joints

Although bolted rail joints are the weakest points in the track structure, some bolted joints are required. These include insulated rail joints that provide the necessary signal sections for track operations to detect vehicle locations, tripping signal circuits, clearance points, and other specific detection networks. An insulated joint separates the ends of the rails to break the signal continuity by use of an insulated end post.

Both non-glued and epoxy glued rail joints have become standard for various conditions.

5.6.2.1 Non-glued Insulated Joints

Standard bolted insulated joints (non-glued) consist of two coated insulated joint bars, thimbles and end post bolted similar to a regular track joint. Standard bolted insulation joints are recommended for use only in bolted jointed track, to provide electrical circuit isolation.

5.6.2.2 Glued Bolted Insulated Joints

Standard glued insulated joints are similar to non-glued joints, except the joint bars are shaped to fit the rail fishing to allow the bars to be glued to the web of the rail. The glued joints provide a longitudinal connection at the rail ends to withstand a rail joint pull-apart in CWR. The glued insulated joints carry the CWR forces through the adjoining insulated bars, and do not rely on the shear forces on the joint bolts.

5.6.2.3 Bolted Joints

In light rail transit systems, jointed track is used only for very sharp curves with restraining rail, maintenance yard facilities, or secondary non-revenue track. Rail joints consist of two joint bars on each side of the rail and a series of track bolts with spring lock washers and heavy square nuts. While joint bar standards vary, there are two general standards: the 4-hole joint bar and the 6-hole joint bar.

At one time, various railroads had different rail drilling spacing for the bolt holes; however, over the years, rail drilling spacing was standardized, as documented in the AREMA Manual. The hole spacing recommended in AREMA should be followed for jointed rails.

5.6.3 Compromise Joints

Compromise joint bars are required to join two dissimilar rail sections. The compromise joint bars are machined or forged to the shape necessary to join the two dissimilar rails. The shape allows both rails to align at the top of rail and the gauge face of both rails. Compromise joint bars, due to design shape, are right- and left-hand installations. The hand designation is defined by the location of the larger rail as seen from the center of the track. To overcome the use of bolted compromise joints in main line track, welding of the two dissimilar sections is considered when the sections are almost identical. Thermite weld kits are manufactured for this situation. A recent design in tee rail-to-girder rail joints is the use of a compromise rail block, in which the rail sections of each rail are machined at each end of a block of steel and a common top of rail and gauge line is developed in the machining process. The compromise block is then welded into the track providing a boltless connection.

5.7 BALLAST AND SUBBALLAST [7]

Ballast, the material used to support the ties and rail, is an important component in the track structure. It is the integral part of the track structure in the roadbed and the quality of the ballast material has a direct relationship to the track support system.

Light rail transit vehicles often exceed 45,500 kilograms (100,000 pounds) placing increased importance on the track structure, particularly the ballast quality and quantity. Superior ballast materials improve the track structure performance and are an economical method of increasing the track strength and the modulus of elasticity

The importance of the quality and type of ballast material, along with standard test methods for evaluating the ballast material, cannot be overstated.

The quality of the ballast will be determined by the choice of rock and the eventual testing of the rock, followed by observing the performance in the track structure. The physical and chemical properties of the ballast rock or stone can be determined by many material tests and performance evaluations. However, the true test of ballast performance is to observe it in the real-life track structure.

5.7.1 Ballast Materials

Ballast should be a hard, dense mineral aggregate with a specific configuration of many fractured faces, angular structure with sharp edges, and with the minimum of elongation.

As a guideline, ballast material for light rail transit use shall be as follows:

- With Concrete Crossties
  - Granite: a plutonic rock with an even texture consisting of feldspar and quartz.
  - Traprock: a dark-colored fine grain non-granitic hypabyssal or extrusive rock.
- With Timber Crossties
  - Granite
  - Traprock
  - Quartzite: granoblastic metamorphic rock consisting of quartz and formed by recrystallization of sandstone or chert by metamorphism.
  - Carbonate: sedimentary rock consisting of carbonate materials such as limestone and dolomite.

Ballast size or gradation is important to match the type of crosstie to be used. The gradation of the ballast determines the sieve size to be used in the process of ballast grading.

Table 5.3 lists the recommended gradations for light rail transit use with concrete and timber crossties.

No. 5 ballast has been used for yard applications with timber crossties to provide an easier walking surface. The smaller gradation may lead to earlier fouling of the ballast and eventual lack of drainage. No. 5 ballast is only recommended when the yard area is honeycombed with an underlying drainage system and substantial surface drainage channels. Yard personnel, walking within the yard area to service vehicles, will most probably be provided with a paved surface walkway.

5.7.1.1 Testing Ballast Materials

Ballast material should be tested for quality through a series of tests undertaken by a certified testing laboratory. The tests should include:

1. *ASTM C88: Soundness of Aggregates by use of Sodium Sulfate ($NaSO_4$).* The sodium sulfate soundness test is conducted with the test sample saturated with a solution of sodium sulfate. This test will appraise the soundness of the aggregate. Materials that do not meet applicable test limits can be expected to

Table 5.3 Ballast Gradations

		Percent Passing								
Size No	Nominal Size Square Opening	76 (3")	64 (2½")	51 (2")	38 (1½")	25 (1")	19 (¾")	13 (½")	10(3/8")	No 4
Concrete Crossties										
24	**64-19 (2½" - ¾")**	**100**	**90-100**	**-**	**25-60**	**-**	**0-10**	**0-5**	**-**	**-**
3	**51-25 (2" - 1")**	**-**	**100**	**95-100**	**35-70**	**0-15**	**-**	**0-5**	**-**	**-**
Timber Crossties										
4A	**51-19 (2" - ¾")**	**-**	**100**	**90-100**	**60-90**	**10-35**	**0-10**	**-**	**0-3**	**-**
4	**38-19 (1½" - ¾")**	**-**	**-**	**100**	**90-100**	**20-55**	**0-15**	**-**	**0-5**	**-**

deteriorate rapidly from weathering and freezing and thawing.

1. ASTM C117: *Test Method for Material Finer than 75 micro-inch (No. 200 Sieve) in Aggregates by Washing (including Dust and Fracture).* The concentration of fine material below the 200 sieve in the ballast material is determined by this ASTM test. Excessive fines are produced in some types of crushing and processing operations and could restrict drainage and foul the ballast section.

2. ASTM C127: *Specific Gravity and Absorption.* Specific gravity and absorption are measured by this test method. Specific gravity in the Imperial (English) measurement system relates to weight and in the metric system to density. A higher specific gravity indicates a heavier material. A stable ballast material should possess the density properties shown in **Table 5.4** to provide suitable weight and mass to provide support and alignment to the track structure. Absorption measures the ability of the material to absorb water. Excessive absorption can result in rapid deterioration during wetting and drying and freezing and thawing cycles.

3. ASTM C142: *Test Method for Clay Lumps and Friable Particles in Aggregates.* The test for friable materials identifies materials that are soft and poorly bonded and results in separate particles being detached from the mass. The test can identify materials that will deteriorate rapidly. Clay in the ballast material is determined by the same test method. Excessive clay can restrict drainage and will promote the growth of vegetation in the ballast section.

4. ASTM C535: *Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*. The Los Angeles abrasion test is a factor in determining the wear characteristics of ballast material. The larger ballast gradations should be tested in accordance with ASTM C535, while ASTM C 131 is the wear test for smaller gradations. Excessive abrasion of an aggregate will result in reduction of particle size, fouling, decreased drainage, and loss of supporting strength of the ballast section. The Los Angeles abrasion test can, however, produce laboratory test results that are not indicative of the field performance of ballast materials.

Table 5.4 Limiting Values of Testing for Ballast Material

Property	Ballast Material							
	Granite	Traprock	Quartzite	Limestone	Dolomitic Limestone	Blast Furnace Slag	Steel Furnace Slag	ASTM Test
Percent Material Passing No. 200 Sieve (maximum)	1.0%	1.0%	1.0%	1.0%	1 0%	1.0%	1.0%	C117
Bulk Specific Gravity (minimum)	2.60	2.60	2.60	2.60	2.65	2.30	2.90	C127
Absorption Percent (maximum)	1.0	1.0	1.0	2.0	2.0	5.0	2.0	C127
Clay Lumps and Friable Particles (maximum)	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	C142
Degradation (maximum)	35%	25%	30%	30%	30%	40%	30%	C535
Soundness (Sodium Sulfate) 5 Cycles (maximum)	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	C88
Flat and/or Elongated Particles (maximum)	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	D4791

1. ASTM D4791: *Test Method for Flat and Elongated Particles.* The test for flat and elongated particles uses one of three dimension ratios. Track stability is enhanced by eliminating flat or elongated particles that exceed 5% of ballast weight. Flat or elongated particles are defined as particles that have a width to thickness or length to width ratio greater than 3.

Table 5.4 lists the recommended limiting values for the ballast material tests. The ballast guidelines for timber and concrete crosstie applications are based on experiences with concrete crosstie ballasted track. The concrete crosstie load characteristics are quite different from the timber crosstie loadings on ballasted track. The concrete crosstie is heavier and less flexible in absorbing impact loads, thus transmitting a greater load to the ballast resulting in a higher crushing degradation load on the ballast particles. The selection of material for ballasted concrete crosstie track is more restrictive and must be limited to granites and traprock. The selection of materials for ballast for timber crosstie track can include all the materials listed in Table 5.4.

Other test procedures exist for testing potential ballast materials, such as the Petrographic Analysis and the Ballast Box Test performed at the University of Massachusetts campus. The services of a qualified certified specialist and testing laboratory in the field of geological materials is recommended to further refine the material selection process and verify the suitability of a quarry for potentially supplying ballast.

5.7.2 Subballast Materials

Subballast material can be classified as crushed stone natural or crushed gravel and sands or a mixture of these materials.Subballast should be a granular base material placed over the top of the entire embankment or roadbed. It is graded and compacted to prevent penetration of the ballast. Subballast material that is impervious should divert most of the water falling on the track to the side ditches to prevent saturation of the subgrade. Subballast material that is impervious requires a layer of sand to be placed between the subballast and the subgrade to release the capillary water or seepage of water below the subballast. A layer of non-woven geotextile will accomplish this as well.

The subballast layer must be of sufficient shear strength to support and transfer the load from the ballast to the subgrade.

5.8 TRACK DERAILS

Track derails are operating protective devices designed to stop (derail) unauthorized vehicles from entering a specific track zone. Generally the track zone is the operating segment of the main line. The protection is placed at all strategic track locations where secondary non-main line operating side tracks,such as pocket tracks, storage or maintenance tracks, and, in some instances, yard lead entry tracks connect to the main line. Derails are occasionally used to prevent vehicle or equipment movement onto portions of track where vehicles, work crews, or equipment are utilizing the designated track space.

Derails should be considered at track connections to the main line where:

- The prevailing track grade of the connecting track is descending toward the main line. The secondary track is used for the storage of unattended (parked) vehicles.
- The secondary track is a storage track for track maintenance vehicles only.
- The connecting track is a railroad industrial siding or at-grade crossing track.

Derails are placed at the clearance point (centers to be determined) of all railroad industrial tracks that connect to either an LRT joint use track or to a railroad main track. Derails are also used at other track locations where they would be likely to prevent or minimize injury to passengers and personnel and/or damage to equipment.

Derails are located so as to derail equipment in the direction away from the main track.

Derails are available in various designs: sliding block derail, hinged block derail, and switch point derail. Derails are generally designed to derail the vehicle in a single direction either to the right or left side of the track.

The sliding and hinged block derails consist of essentially two parts: the steel housing and the derailing guide block. The sliding derail is generally operated with a connecting switch stand. The hinged derail is operated manually by lifting the derailing block out of the way or off the rail head.

The switch point derail is exactly as described, a complete switch point (or two points) placed in the track to derail when the switch point is open.

As a guideline, the type of derail to be used depends upon the site-specific conditions and type of protection to be provided. Main line track exposed to the intrusion of heavily loaded cars, multiple car trains, physical track conditions that permit the intruding cars to gain momentum in advance of the derail, and tight curvature on the siding track lead to the occasional failure of block derails. The switch point derail provides the greatest assurance that all wheels of the vehicle will be derailed.

5.9 RAIL EXPANSION JOINTS

Continuously welded rail in long strings does not expand or contract with changes in temperature, unless there is a break in the rail. This type of installation introduces high thermal stress in the rail as the temperature changes.

In certain structures, the interaction between the CWR and the structure makes it desirable to limit rail stresses from thermal forces. This can be accomplished by allowing the rail to move freely within defined zones. A combination of low-restraint track fasteners and rail expansion joints allows this movement to take place safely. The use of low-restraint fasteners at structural expansion joints allows the structure to "breathe" without overstressing the rails. The rails must also be anchored between expansion zones with high-restraint fasteners, in order to transfer acceleration and braking forces into the structure.

In high-restraint areas, a conventional direct fixation fastener is utilized, and the structure is designed to accept the thermal stress loads generated by movement of the structure. The expansion or contraction of low-restraint rail emanates from the high-restraint zone and is bounded on the other end by a rail expansion joint.

Rail expansion joints are designed to allow for a specific length of thermal rail expansion and contraction to occur. One end of the expansion joint is fixed and connected to a rigid no-movement portion of rail. The other end consists of the expandable moveable rail which is allowed to slide in and out of a designed guideway. The expansion joint simulates a switch point and stock rail type of installation with the expansion rail being the curved stock rail.

Expansion joints in the track system present problems, from both a track maintenance and an environmental perspective. Due to the discontinuous running rail surface and the special trackwork sliding rail joint component, extra maintenance is required to maintain the joint and adjacent rails and to monitor the position of the loose rail end to ensure that sufficient space is available for further expansion. The specific design of the expansion joint within the discontinuous running rail surface introduces additional noise and vibration.

As a guideline, rail expansion joints in ballasted track or direct fixation track are only recommended for long bridges or aerial structures. They are also needed at the fixed span approach to a movable bridge.

Exceptions to this guideline include embedded track on an aerial structure, wherein the rail is an integral part of the deck structure and the design does not allow the structure to move independently from the rail. In this situation, an embedded expansion rail joint at the expansion end of the structure is a definite requirement. For this reason, the use of embedded track on an aerial structure is not recommended and should be avoided in the initial planning phase when considering the types of transit operation modes.

5.10 END OF TRACK STOPS

As important as the tangent and curved track is throughout the transit system, the end of track cannot be overlooked. There is a requirement to protect the passengers and pedestrians (on and off the vehicles), the operators, the vehicles, the track and surrounding structures. Bumping posts, stops, and retarders are used to prevent an accidental overrun vehicle derailment at the end of track. The capabilities of the track stops are limited to halting the vehicle entirely with minimal damage to the vehicle and stopping the vehicle with the minimum of impact to the passengers on board.

The end stop is the point of impact, the location where kinetic energy has to be dissipated. The kinetic energy is determined considering the mass or weight of the vehicle or vehicles (train) and the velocity of the vehicle or train. The kinetic energy (KE) can be calculated using the following formula:

$$KE = \frac{M \times V^2}{2}$$

$$= \frac{200{,}000\text{kg} \times (4.47)^2}{2}$$

$$= 1{,}998{,}090\text{J or } 1{,}998\text{kJ}$$

where: M = mass of the vehicle or train

= 200 Tonnes (1 Tonne = 1000 kg)

V = velocity of vehicle or train

4.47 meter/second (10 MPH)

To safely absorb this amount of energy with little damage to the vehicle (train) or injury to passengers or the operator requires an elaborate end stop with extensive capacity.

To absorb this amount of energy without causing severe injury to operator or passengers, an acceptable deceleration rate must be selected. The transit agency should select the rate of deceleration; a rate of 0.3 g is an acceptable deceleration. The establishment of a deceleration rate will consider the likelihood of injury to passengers and operators and damage to the vehicles, third parties, and surrounding structures. Each agency's requirements are studied individually and are site specific

Assuming the 0.3g deceleration rate is selected, the next decision is to determine the type of end stop capable of providing this deceleration rate.

To absorb 1,998 kJ of kinetic energy at a deceleration rate of 0.3 g, the distance traveled after initial impact would have to be 3.39 meters (11.12 feet) calculated in the following manner·

$$\text{Distance} = V \bullet t + \frac{d \bullet t^2}{2}$$

V= velocity of train in m/sec

t= time to stop in seconds

d= deceleration rate$(-x \bullet 9.81 \text{ m/sec}^2)$

x= deceleration negative rate (selected)

$$t = \frac{V}{d^2} = \frac{4.47}{0.3 \times 9.81 \text{ m/sec}^2}$$

$$= 1\ 52 \text{ seconds}$$

$$\text{From Above Distance } = V \bullet t + \frac{d \bullet t^2}{2}$$

$$= (4.47 \bullet 1.52) + \frac{(-0.3 \times 9.81) \bullet (1.52)^2}{2}$$

$$= 3.39 \text{ meters (11.12 feet)}$$

The standards for end stops consist of the following:

- Warning Signs
- Fixed Non-Energy Absorbing Devices
- Fixed Energy Absorbing Devices
- Friction Energy Absorbing Devices

5.10.1 Warning Signs

Ideal conditions, alert operators, no mechanical vehicle or signal failures, and a well-illuminated warning sign should be adequate for the train operator to bring the vehicle or train to a safe controlled stop.

5.10.2 Fixed Non-energy Absorbing Devices

Most fixed non-energy absorbing end stops (bumping posts) do no more than delineate the end of track. The end stops appear sturdy since they are bolted to the rail, however, they have little ability to absorb anything but a very minimal amount of kinetic energy. Impact often results in breaking of the rail, potential derailment, and damage to the vehicle.

A positive fixed non-energy stop will halt heavy vehicles or trains exists at the expense of vehicle damage and personnel injury. These stops consist of a solid concrete and steel barriers generally located at end of tracks in the older railroad stations.

5.10.3 Fixed Energy Absorbing Devices

Fixed energy absorbing devices can be either non-resetting or resetting.

5.10.3.1 Non-resetting fixed devices

Non-resetting fixed devices (bumping posts) include sand traps, ballast mounds and timber tie stops. These devices dissipate the kinetic energy upon vehicle impact. Sand traps and ballast mounds are effective in stopping large loads or trains; however, derailment of the initial vehicle is inevitable. Under severe cold weather conditions the sand and ballast can freeze, reducing the cushioning effect and possibly causing additional vehicle damage. The barrier would have to be rebuilt after experiencing an impact.

5.10.3.2 Resetting Fixed Devices

Resetting fixed devices are self-resetting and contain an energy-absorbing feature, such as a hydraulic, elastomeric, or spring shock absorber. Resetting stops are limited in amount of energy the shock absorber can dissipate and the stop structure's capability to withstand the forces at impact. As noted above, the displacement distance of the stop at impact governs the magnitude of g force—the longer the distance the lower the g force The anchoring stability of the end stop to the substrata governs the amount of energy that can be absorbed by the stroke of the shock absorber.

5.10.4 Friction (or Sliding) End Stops

Friction type end stops absorb the kinetic energy of stopping a vehicle or train by sliding along the end of track (see **Figure 5.10.1**). This sliding action converts the energy to friction heat at the rail surface. The friction end stops consist of two types:

- Units that are clamped to the rail
- Units that are mounted on skids that slide with the weight of vehicle upon them, dissipating the energy between the wooden skids and the concrete base of track structure.

Friction end stops have the highest energy absorption of all regularly installed structures. Friction stops can be designed to cover a wide range of energy absorption situations from single vehicle to multi-vehicle trains of various mass. The combination of resetting shock absorbers and friction end stops can allow a friction end stop to accept light impacts without negotiating the friction end stop while providing the higher friction end stop protection for ultimate situations.

Transit conditions have potential use for the various end of track stops, as follows:

- Main Line End of Track (Ballasted-Direct Fixation): friction/sliding end stop with resetting shock absorber, if track sliding distance available.

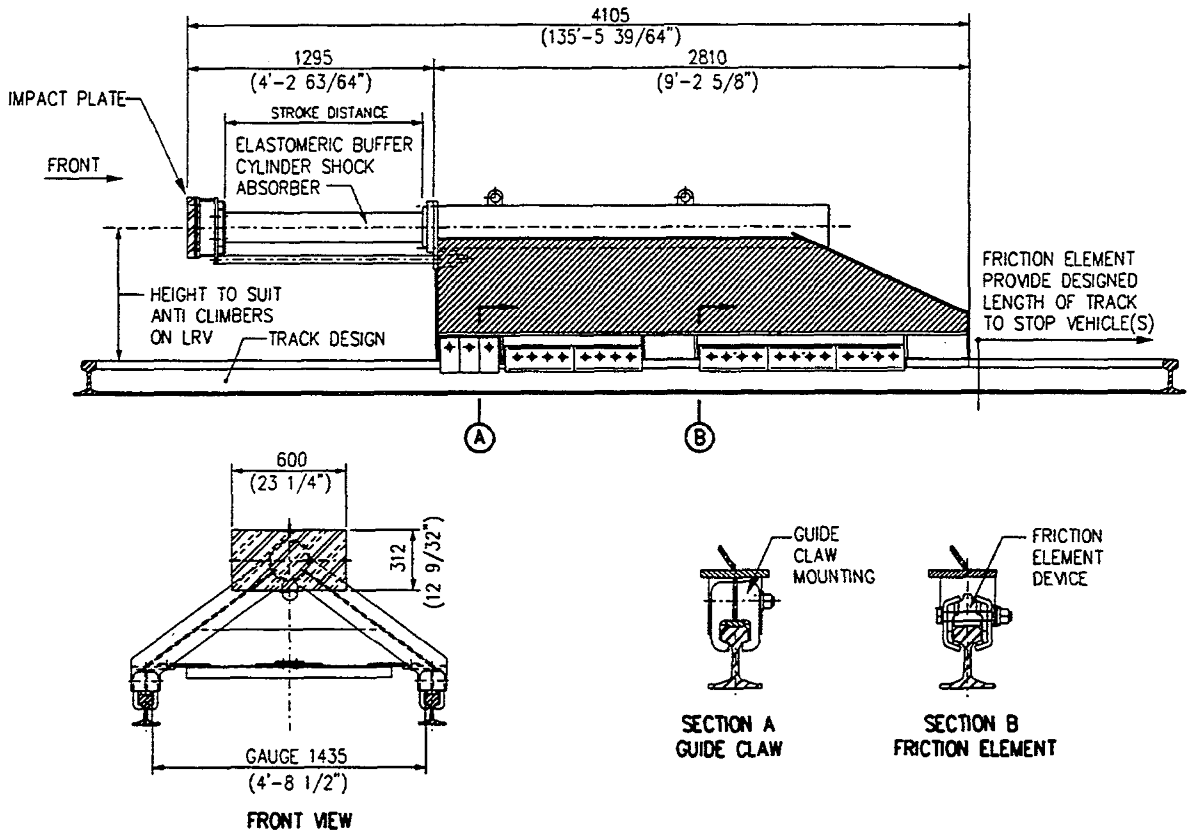


Figure 5.10.1 Friction Element Buffer Stop [8]

- Main Line End of Track (Embedded): Same as above, if conditions warrant, or a resetting track stop anchored to the substrata.
- Main Line End of Track (Aerial-Direct Fixation): friction/sliding end stop with resetting shock absorber; track distance must be provided.
- Yard Tracks (Maintenance Tracks): fixed non-energy absorbing devices, bumping posts anchored to the track
- Storage Tracks: resetting fixed devices anchored to the track.
- Maintenance Shop Tracks: Fixed Resetting Energy Absorbing Device anchored to the structure floor. (Non-movable).

5.11 REFERENCES

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Chapter 6—Special Trackwork

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CHAPTER 6—SPECIAL TRACKWORK

6.1 INTRODUCTION

Light rail vehicles, like all steel flange wheeled railway equipment, need to be able to transfer from one track to another or to cross other tracks. The fabricated track systems needed to support and steer the car at these locations are collectively called special trackwork. It is presumed that most readers of this chapter are generally familiar with the layout and use of common special trackwork terms. Readers who are new to the topic can find a brief primer on basic concepts and terminology in Section 6.2.1.

Readers with a background in railway track design will note pronounced differences between requirements for special trackwork for light rail transit (LRT) systems and those for other types of railways. In general, designers can expect to find that special trackwork design requirements on a light rail system will be more numerous and more complex than those encountered on other types of railways. In addition, sources of supply will be more limited than they may be used to.

Most turnouts that are available for tangent track are standardized for simplified manufacture and installation, both of original equipment and replacements for worn components. These turnouts are intended for installation in tangent track, without any vertical curvature. One of the most common design deficiencies is the placement of turnouts within horizontal or vertical curves. Construction and maintenance of curved track is difficult and expensive. Superimposed special trackwork only exacerbates those problems. It is recommended that standardized trackwork be used on flat tangent track whenever possible.

Light rail systems that are located in urban streets, particularly those that are located in Central Business Districts with narrow rights-of-way, often have sharp curves. This constraint often requires light rail special trackwork to be designed for a specific location, with unique parts.

6.2 DEFINITION OF SPECIAL TRACKWORK

Special trackwork is customarily defined as "all rails, track structures and fittings, other than plain unguarded track, that is neither curved nor fabricated before laying." [1] Hence, any track can be considered special trackwork that is built in whole or part using rails that are machined, bent, or otherwise modified from their as-rolled condition. This includes any additional track components that may take the place of rails in supporting and guiding the wheels, as well as miscellaneous components that may be attached to the rails to fulfill the functions required. The term is often contracted and called simply "specialwork."

In general, the following items are customarily included in special trackwork:

- Turnouts and crossovers, including switches, frogs, guard rails, stock rails and closure rails; rail fastening assemblies unique to turnouts; and miscellaneous components associated with turnouts, including switch rods and gauge plates. Crossover tracks, double crossovers, and single and double slip switches are included in this category.
- Track crossings that permit one track to cross another at grade. Such crossings can be designed as a rigid block or can include movable center points. By

definition, slip switches include a track crossing.

- Restraining rail, either bolted to a parallel running rail or supported independent of the running rail.
- Shop curved rail of any type, including rails that are precurved in the horizontal plane, the vertical orientation, or both.

Turnouts, crossovers, and track crossings will be addressed directly in this chapter. Information on restraining rail and shop curved rail can be found in Chapters 4 and 5.

6.2.1 Basic Special Trackwork Principles

The most common form of special trackwork is the ***turnout***, which permits two tracks to merge with each other. A simplified layout of a turnout is illustrated in **Figure 6.2.1**. The turnout itself consists of several fundamental elements:

- *The switch point rails* (often called either the switch points or the point rails) are the movable rails that flex back and forth and intercept the wheel flanges to direct them to the appropriate track. In its usual form, a switch point rail consists of a plain rail that has been machined and bent into an elongated wedge shape that is sharp on one end. This pointed end is known as the "point of switch." The opposite end is known as the "heel of switch." Switches come in various lengths and can be either straight or curved. In general, the longer the switch point rail, the more gradual the angle of divergence from the main track and the faster the rail vehicle can travel through it. The switch point rails, together with the stock rails (described below) and associated fastenings and mechanisms, are collectively called the switch.
- *The stock rails* are the rails which the switch point rails lay against when in the closed position. The stock rails are otherwise ordinary rails that are machined, drilled and bent as required to suit the design of the switch point rails.

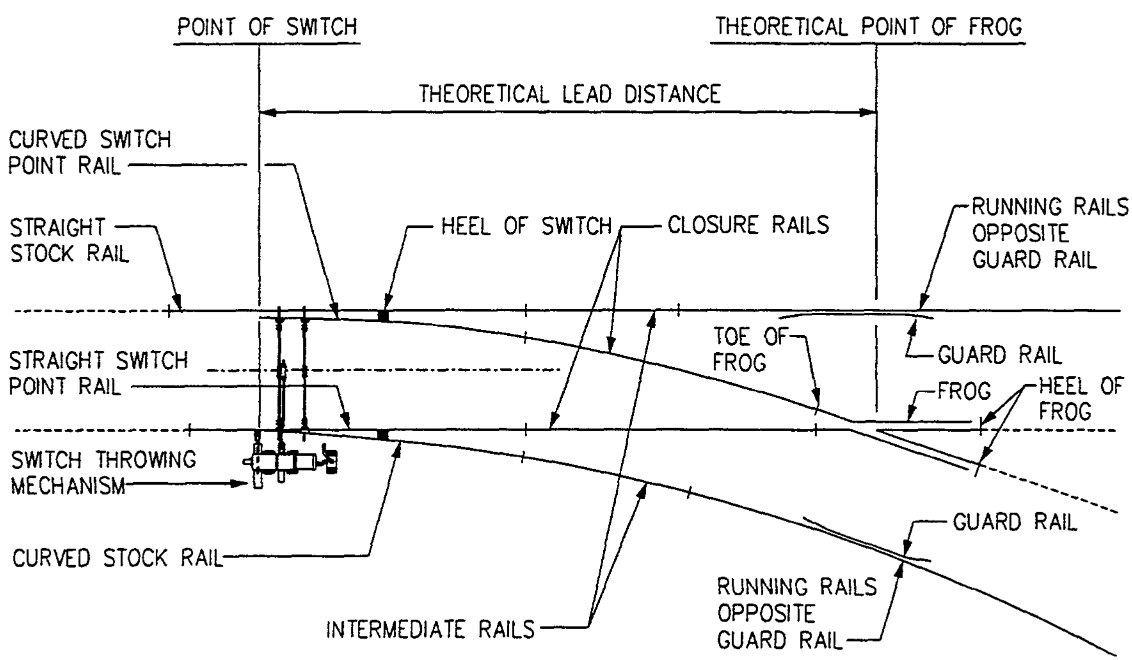


Figure 6.2.1 Turnout Layout

- *The frog* is an assembly placed where one rail of a track must cross a rail of another. Openings called flangeways must be provided through the top surface of the frog so that the flanges on the vehicle wheel can pass through. The intersection of the gauge lines of the two intersecting rails is known as the theoretical point of frog. The theoretical point of frog would be a razor sharp tip that would quickly wear and fracture in service. Therefore, the intersecting rails are cut back a short distance to a location known as the actual point of frog, where the metal will have enough rigidity to withstand the effects of service wear. The end of the frog closest to the switch rails is known as the toe of frog; the opposite end is known as the "heel of frog." Typically, both rails passing through a frog are straight, although it is possible for one or both rails to be curved. Straight frogs are commonly designated by a number that indicates the ratio of divergence of one rail to the other. In a Number 10 frog, the two rails will diverge at a ratio of one unit laterally for every ten units of frog length. In a Number 8 frog, the divergence ratio will be one to eight, etc. The higher the frog number, the more acute the angle of divergence and the faster the rail vehicle will be able to travel through it.

- *The closure rails* are the straight or curved rails that are positioned in between the switch and the frog. The length and radius of the closure rails are dictated by the angles of the switch and the frog. Combinations of short switches with large angles and similar frogs will result in a sharp radius curve through the closure rail areas that will limit vehicle speed. The distance between the point of switch and the point of the frog measured along the straight or main track closure rail is known as the turnout *lead* distance.

Additional components that are common on a turnout include:

- *Guard Rails* are supplemental rails, placed inboard of the main running rails that support the railcar wheels. They define a narrow flangeway to steer and control the path of the flanged wheel. Guard rails are positioned opposite the frogs so as to ensure that the wheel flange does not strike the point of frog or take the "wrong" flangeway.

- *Heel Blocks* are splicing units placed at the heel of the switch that provide a location for the switch to pivot as well as a fixed connection between the intersecting rails.

- *A switch operating device.* Switch rails can move from one orientation to another by either a hand-operated switch stand or a mechanically or electro-mechanically operated switch machine. In both cases, the switch machines are positioned at the beginning of the turnout opposite the tips of the switch rails.

Various arrangements of individual turnouts create various track layouts, thereby permitting alternative train operation scenarios:

- A single crossover (**Figure 6.2.2**) consists of two turnouts positioned in two tracks that allow the vehicle to go from one track to another. The two tracks are usually, but not always, parallel, and the turnouts are usually identical.

- A double crossover (**Figure 6.2.3**) consists of two crossovers of opposite hand orientation superimposed upon each other. In addition to the four turnouts involved, a track crossing (see below) is needed between the two main tracks. A double crossover is used only when it is necessary to be able to switch from one track to another in either direction and there is insufficient space to install two independent single crossovers of opposite hand orientation.

Another common type of special trackwork is the ***track crossing***. As the name implies, this specialwork permits two tracks to cross each other. Track crossings are often called *crossing diamonds* or simply *diamonds,* due to the plan view shape that they have when looking diagonally across the tracks (see **Figure 6.2.4**). The intersecting angle between the two tracks can be 90° or less, but crossings under approximately 15° are rarely encountered. In its simplest form, a track crossing is simply four frogs arranged in a square or parallelogram. The tracks through a crossing can be either straight or curved. Straight tracks are preferred since it makes the unit symmetrical, thereby simplifying design, fabrication and maintenance. If the crossing angle between straight tracks is 90°, then the four frogs will be identical. If the angle is not 90°, then the crossing will be elongated along one diagonal axis called the "long diagonal" and the "end frogs" will be different from the "center frogs."

If the angle of the intersecting tracks is less than that in a Number 6 frog (9° 31' 38"), it is usually necessary to use a movable point crossing. Movable point crossings incorporate movable rails in the two frogs closest to the center of the crossing. Depending on the position of these movable rails, a flangeway will be provided for one track or the other, but not both simultaneously. Movable point frogs are needed on flat-angle crossings since it is otherwise impossible to ensure that the wheel flange will follow the correct flangeway path through the center frogs of the crossing diamond. The movable rails in a movable point crossing are called *knuckle rails* and are usually operated by the same type of equipment used to move switches.

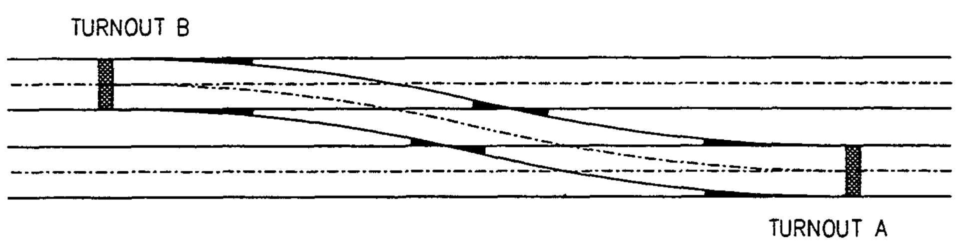


Figure 6.2.2 Single Crossover—Two Turnouts

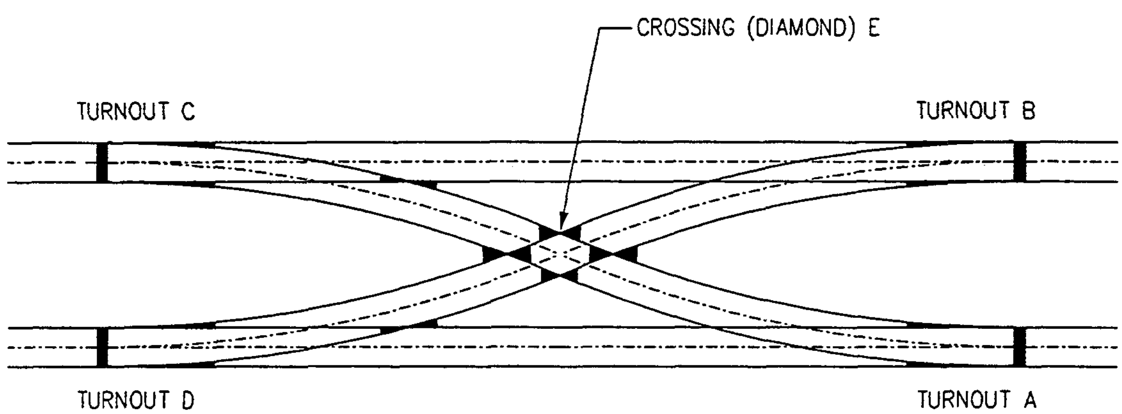
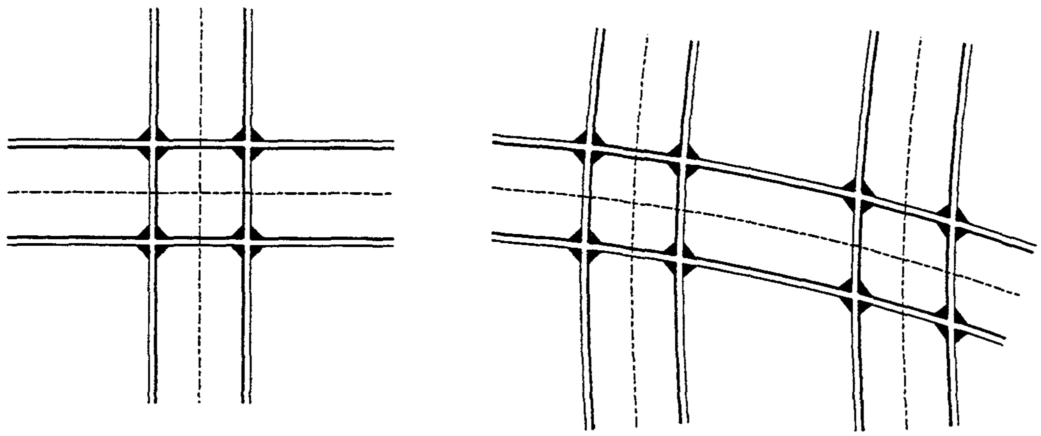


Figure 6.2.3 Double Crossover—Four Turnouts and Crossing



SINGLE TRACK CROSSING (DIAMOND)

DOUBLE TRACK CROSSING (DIAMONDS)

Figure 6.2.4 Single-Track and Double-Track Crossings

If it is necessary to be able to switch from one track to another at a flat-angle crossing and space constraints make it impossible to provide separate turnouts outside of the limits of the diamond, a *slip switch* can be installed. A slip switch superimposes two switches and curved closure rails on top of an elongated track crossing as shown in **Figure 6.2.5**. A *double slip switch* provides that same routing capability along both sides of a track crossing as shown in phantom line on the figure.

Combinations of turnouts and track crossings are used to produce route junctions. Junctions can range from very simple to very complex as seen in **Figures 6.2.6 to 6.2.8**. The most complex junctions can occur in the central business districts of urban areas when two double-track routes cross one another. **Figure 6.2.7** illustrates a "Grand Union," an extremely complex arrangement that permits a vehicle entering a junction from any direction to exit it on any of the other three legs. A junction that resembles a "T" intersection would require a "half grand union" (see **Figure 6.2.8**) to provide the same routing flexibility. Such complex junction layouts were common on traditional streetcar systems and have been used on some modern light rail systems when space was extremely limited.

Lap turnouts can be used to achieve a more compact track layout in constrained locations. In a lap turnout, as seen in **Figure 6.2.6**, the switch rails for a second turnout will be placed between the switch and the frog of the initial turnout. This introduces a third frog where a closure rail of the first turnout crosses a closure rail of the second.

Lap turnouts, movable point crossings, slip switches, and double slip switches are all very costly to design, fabricate, install, and maintain. A more economical track system is achieved when the special trackwork consists only of turnouts and simple track crossings.

6.3 LOCATION OF TURNOUTS AND CROSSOVERS

The ideal location for turnouts, crossings and crossovers is in flat and straight sections of track. If special trackwork is installed in track with horizontal curves, superelevation, or

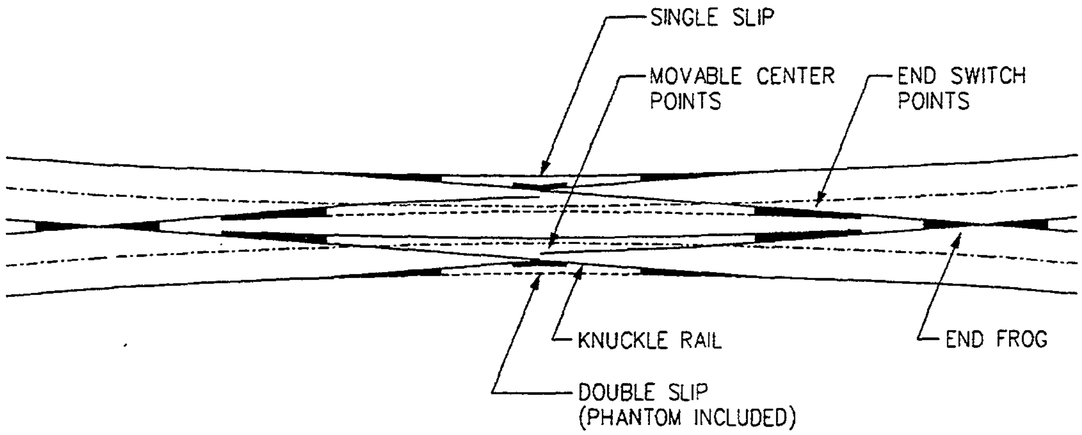


Figure 6.2.5 Single Slip Switch

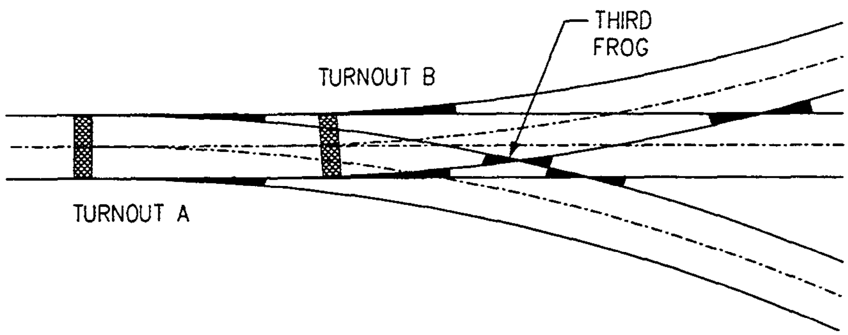


Figure 6.2.6 Double Switch Lap Turnout—Three Frogs

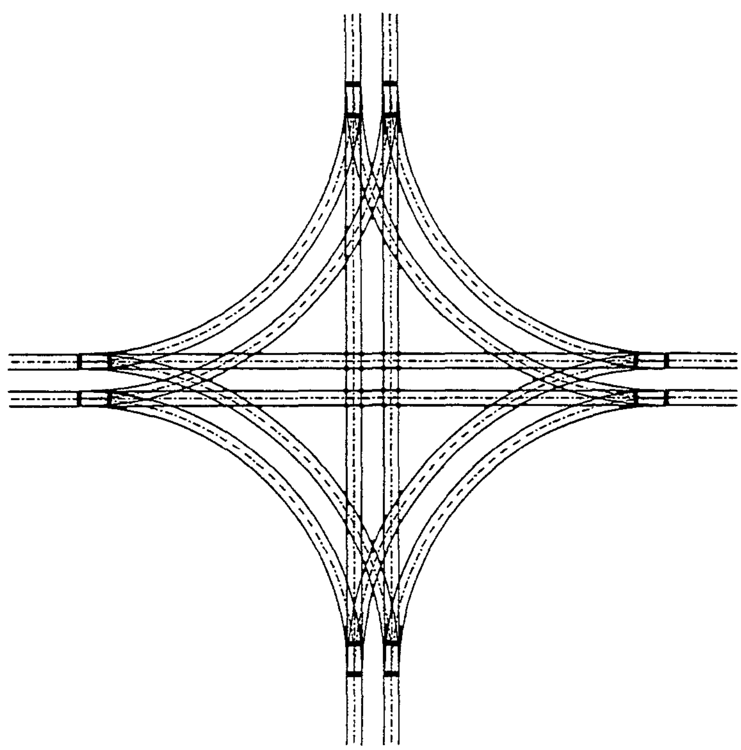


Figure 6.2.7 Full Grand Union

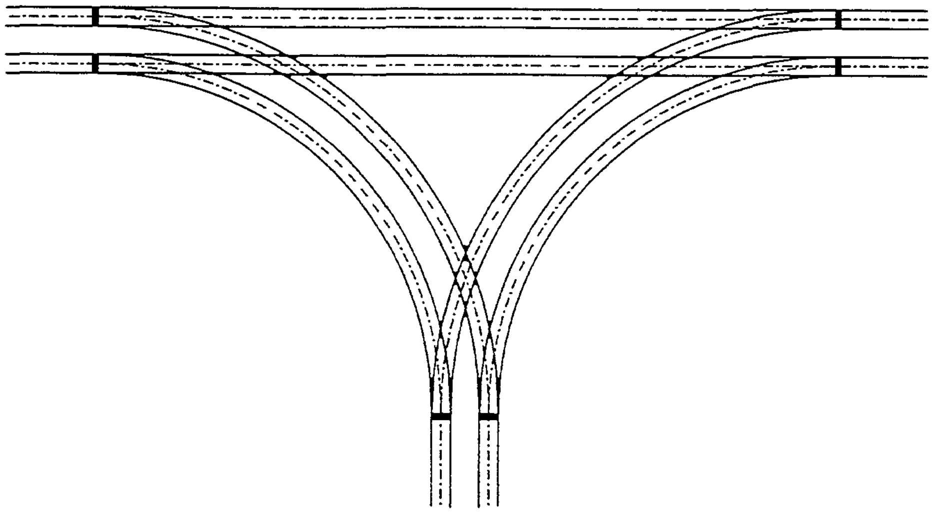


Figure 6.2.8 Half Grand Union

vertical curves, the ability of the trackwork to perform in a satisfactory manner is compromised. Trackwork designers should work closely with their counterparts who are defining transit operations requirements and setting route geometry, so that turnouts and crossovers are not placed in difficult locations and the overall requirements for special trackwork are minimized.

6.3.1 Horizontal Track Geometry Restrictions

6.3.1.1 Adjacent Horizontal Track Geometry in the Vicinity of a Switch

Switch point rails direct vehicle wheelsets in an abrupt change of direction, making it highly desirable that wheels be rolling smoothly as they approach the switch. To best ensure that wheel flanges can be smoothly intercepted by switch point rails, tangent track should be placed immediately in front of the switch. The absolute minimum length of tangent track in advance of the point of the switch should be no less than 3 meters (10 feet) and much greater distances —10 to 15 meters (33 to 50 feet)—are desirable. If a guarded curve is located in advance of the switch, the turnout should be positioned with the point of switch beyond the limits of the restraining rail.

Horizontal curves that are located beyond the heel of the frog should generally be positioned beyond the last long tie of the switch set. Horizontal curves can be placed on the long timbers within 0.5 meters (20 inches) of the heel joint of the frog. However, special switch tie or track concrete layout will be required. If the curve is guarded, and the restraining rail is on the frog side of the alignment, the curve should be located so that the restraining rail terminates prior to the heel joint of the frog. If this is not possible, the restraining rail should be run into the frog and be continuous with the frog wing rail to provide continuous guarding action.

6.3.1.2 Turnouts on Curves

Turnouts can be constructed within curved track in difficult alignment conditions. Railroad operating personnel will state, however, that turnouts on curves provide a poor quality ride. Track maintenance personnel contend that the curved turnouts consume a disproportionate amount of their maintenance budgets. Therefore, turnouts and crossovers should only be located in horizontally tangent track, except under the most unusual and constrained conditions. This will ensure that the track geometry through the special trackwork unit will be as uniform as possible, thereby improving wheel tracking and extending the life of both the special trackwork unit and the vehicle that operates over it.

A turnout on a curve must be custom designed. The design objective should be to provide an alignment that is as smooth and uniform as possible. Designers should note that this turnout geometry will differ appreciably from ordinary turnouts located along tangent track. Parameters such as turnout lead distance and closure rail offsets will be distinctly different from those of a standard lateral turnout with the same frog number. Several good books exist on the subject, including Allen's <u>Railroad Curves & Earthwork</u>.

6.3.1.3 Track Crossings on Curves

Either one or both tracks of a crossing (diamond) may be located in horizontally curved track if required by the selected alignment. This is often a requirement at a route junction. At such locations, it is typically allowable to have one or both sides of the track crossing on a curved alignment. In general, however, curved crossings should be avoided because they are typically one-of-a-kind units and hence very expensive to procure, maintain, and ultimately replace. In addition, the crossing must be flat, without superelevation. This has a detrimental impact on the operation of trains over curved track.

6.3.1.4 Superelevation in Special Trackwork

Superelevation should not be used within any turnout, crossover, or track crossing, even if the main track is located on a curve. The correct amount of superelevation for one hand of the turnout will be incorrect for the other and an excessive underbalance or overbalance could result. A particularly dangerous situation occurs with a turnout to the outside of the curve, where a severe negative superelevation situation could be created on the diverging track. In ballasted track, normal deterioration of the track surface could quickly result in the diverging track becoming operationally unsafe.

When a superelevated curve is required beyond the frog of a turnout, the superelevation should begin beyond the last long tie of the switch set in a ballasted track turnout. In a direct fixation track turnout, superelevation can physically begin earlier, although typically not within 500 millimeters (20 inches) of the heel joint of the frog.

6.3.2 Vertical Track Geometry Restrictions

Turnouts, crossovers and track crossings should be located on tangent profile grades whenever possible. This is because the critical portions of a turnout—the switch and the frog—are too rigid to conform to a vertical curve, which will cause the switch points to bind. The area between the switch and the frog can theoretically be curved vertically, but this practice is discouraged since ordinary construction tolerances make it difficult to confine the curvature to the closure rail area. Vertical track curvature outside of the turnout area should also be restricted; the absolute minimum distance from the switch and frog will depend on the type of track structure. In the case of ballasted track, for example, it is not practical to introduce any vertical curvature until after the last long tie of the switch set.

In difficult alignment conditions, vertical curvature at or near a turnout location may be necessary. If it is not possible to avoid a vertical curve within a turnout, every effort should be made to avoid non-standard track components, such as switch point rails or frogs, that must be shop-fabricated with a vertical curve. Generally, special designs can be avoided if the middle ordinate of the vertical curve in the length of any switch point rail or frog is less than 1 millimeter (0.040 inches).

6.3.3 Track Design Restrictions on Location of Special Trackwork

While special trackwork can be required in ballasted, direct fixation, and embedded track sections, turnouts are most economical to procure, construct and maintain in ballasted track. Alignment design should minimize special trackwork requirements in direct fixation and embedded track environments, because these elements are expensive to procure, construct and maintain. Exceptions can be made, for example, when route geometry forces a particularly complex special trackwork layout with multiple turnouts and track crossings. It is often particularly difficult to design a satisfactory switch tie layout under such complex layouts and even more difficult to renew defective switch ties during subsequent maintenance cycles. In such special circumstances, the use of direct fixation special trackwork track may be preferable to a ballasted configuration.

Yard trackage, which is usually ballasted, often requires that successive turnouts be constructed close to each other. The track designer should verify that turnouts are sufficiently spaced to permit standard switch ties to be installed and to permit maintenance personnel to renew individual switch ties. When special switch tie arrangements are required, the track designer should either detail the tie layout or require the track fabricator to provide a submittal of the proposed layout In the latter case, the track designers should be certain ahead of time that a workable tie layout is possible. It is absolutely essential that switch ties supporting switches are perpendicular to the straight track. This is a problem when switches are placed immediately beyond a frog on the curved side of a turnout.

Special trackwork in embedded track can be particularly complicated and should be minimized. Route intersections within street intersections can be phenomenally complex and require intricate plans and pre-delivery assembly on the factory floor. When special trackwork must be located in embedded track, it should be positioned so that pedestrians are not exposed to switch point rails and switch operating mechanisms and frogs are not positioned in pedestrian paths. Reliable signal systems and switch operating mechanisms for embedded track turnouts are also difficult to procure and maintain as noted in Sections 6.3.4.1 and 6.5.4.3.

6.3.4 Interdisciplinary Restrictions on Location of Special Trackwork

Special trackwork should be located so as to minimize requirements for special Overhead Contact System (OCS) and train control/ signaling system structures and devices.

6.3.4.1 Overhead Contact System Interface

The installation of catenary is complicated by the presence of turnouts and crossovers. Additional wires, pull off poles, and insulating sections are needed to provide a smooth ride for the pantograph. Electrically isolating the opposite bound main tracks is particularly difficult at double crossovers if the adjacent tracks are close together. These conditions should be discussed with the catenary designer to ensure that the catenary can be economically constructed.

6.3.4.2 Train Control/Signaling Interface

Switch machines that comply with North American signal system standards are difficult to obtain for fully guarded open track turnouts and are not available for tongue switch embedded track turnouts. The principal problem is that proper switch locking is required for automatic routing at design track speed. Many rail transit systems require train operators to stop, verify switch position, and then proceed at any turnout that is not equipped with a locking switch device. This causes delays and, for this reason alone, designers are strongly encouraged to avoid these types of turnouts. In addition, the track circuits that are needed to determine track occupancy are more difficult to install and maintain in embedded track since the embedment material will restrict access to key areas where unintended shunts can cause signals to drop. Accordingly, embedded track switches should be avoided to the maximum degree possible.

Insulated rail joints in special trackwork can be especially complicated, particularly if they must be located in guarded track or in and around crossing diamonds. The trackwork designer should coordinate with the signal designers to verify that a workable insulated joint layout is possible. In many cases, a workable track plan cannot be properly signaled and the route geometry must be redesigned.

6.3.5 Miscellaneous Restrictions on Location of Special Trackwork

6.3.5.1 Construction Restrictions

The construction limits of any trackwork contracts should not be located within any special trackwork unit, including guarded curved track. This will ensure that one contractor will be responsible for the uniformity of the horizontal and vertical track alignment through the special trackwork unit.

6.3.5.2 Clearance Restrictions

Special trackwork should be located with adequate clearances from trackside obstructions. For example, unless the vehicles are equipped with automatic bridge plates for pedestrian access, tangent track is required alongside platforms to meet the tight tolerances required by Americans with Disabilities Act (ADA). If a station platform is located ahead of a point of switch, the minimum tangent distance between the end of the platform and the point of switch should be equal to the truck center length of the LRV plus the car body end overhang. Refer to Chapter 3 for additional guidance on special trackwork clearances.

6.3.5.3 High Volume of Diverging Movements

Track designers should be very cautious whenever the route geometry results in a preponderance of the traffic passing through the curved side of a turnout. High traffic volumes through the curved side of a switch will result in accelerated wear of the switch point and the adjoining stock rail. Whenever possible, turnouts at junctions should be oriented to guide the branch with the more frequent or heavier traffic over the straight part of the switch.. If the traffic is (or will eventually be) approximately equal, consideration should be given to an equilateral turnout design as discussed in Section 6.4.4. This will reduce maintenance of the switch points.

Turnouts at the end of a double-track segment should be oriented to guide the facing point movement over the straight side of the turnout. If this results in an unsatisfactory operating speed for the trailing movement, the designer should consider using either a equilateral turnout design or a turnout with a flatter divergence angle and curve than might ordinarily be provided. Ordinarily, facing point diverging movements should be limited to situations where the single-track section is temporary and the double-track section is to be extended.

6.3.5.4 Track Stiffness

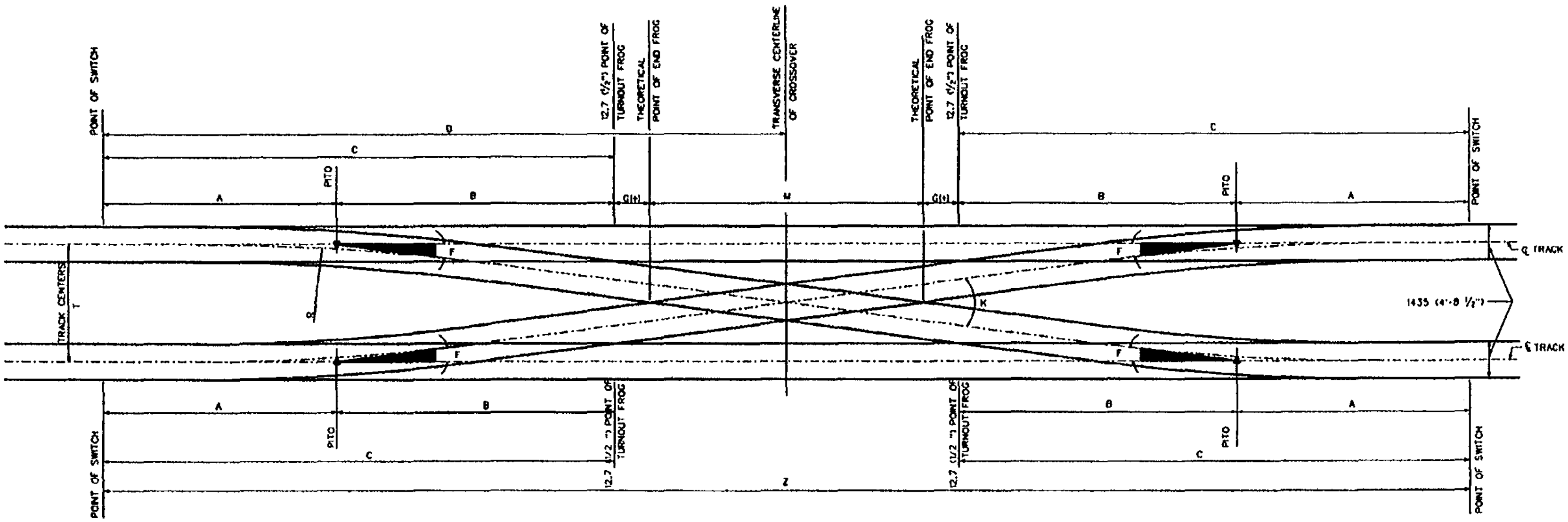
Ballasted turnouts, crossovers, and crossing diamonds have a considerably higher track modulus than ordinary ballasted track due to their mass and the frequent interconnections between rails. Nevertheless, they are still more resilient than either direct fixation or embedded track layouts. Because of this differential, ballasted track turnouts located close to interfaces with stiffer track structures will ride poorly and require more frequent surfacing, particularly if vehicle speeds are relatively high. To avoid these circumstances, main tracks where vehicles operate at speeds greater than 100 kph (62 mph) should not have specialwork units located within 75 meters (233 feet) of a transition between ballasted track and a more rigid track structure. As a guideline, this distance can be reduced in areas where modest operating speeds are contemplated. A minimum travel time of 3 to 5 seconds between the special trackwork unit and a more rigid structure is recommended. Design exceptions will require stiffening of the ballasted track or retrofitting of the adjoining track to be more resilient.

6.3.5.5 Noise and Vibration Issues

Even well-designed special trackwork can be a source of noise and vibration. As such, special trackwork installations are undesirable in the vicinity of residential buildings, schools, hospitals, concert halls, and other sensitive noise and vibration receptors. If special trackwork must be located in such areas, investigation of possible noise and vibration mitigation measures should be undertaken. Such investigations should include the ramifications of repositioning the special trackwork away from the area of concern.

6.4 TURNOUT SIZE SELECTION

Track designers have a wide array of standard turnout geometric configurations to choose from when considering route alignment. While not all transit systems can use the same menu of turnouts and crossovers, the designer can usually achieve an acceptable route alignment without resorting to special designs. Using standard, off-the-shelf, and service-proven materials will reduce the probability that future maintenance will be complicated by the need to purchase expensive one-of-a-kind products. This also avoids the situation where essential replacement parts may not be available when needed. **Figures 6.4.1 to 6.4.4** show standard turnouts and crossovers. Situations will arise when a non-standard turnout design is needed. In such cases, justification should be documented. This validation should include: the reasons why a particular turnout size is required; what alternatives were investigated; why standard options were unacceptable; and the ramifications of using a smaller turnout, including its affect on vehicle operations, signaling systems, and OCS systems. Consideration should also be given to procurement of a spare assembly along with the original unit, so as to save the design and tooling costs that would be incurred to purchase the unit at a later date. This provides an immediate replacement part if one is needed.



GEOMETRIC SCHEMATIC - SINGLE OR DOUBLE CROSSOVER

NOT TO SCALE

TURNOUT DATA TABLE - BALLASTED OR DIRECT FIXATION TRACK											
TURNOUT NUMBER	FROG ANGLE F	SWITCH LENGTH AND TYPE	LEAD C	PS TO PITO A	PITO TO 1/2" PF B	CENTERLINE RADIUS R	SWITCH			FROG	
							POINT ANGLE FROM TAN	HEEL ANGLE	RADIUS	TOE LENGTH	HEEL LENGTH
6	9° 31'38"	3962.4 (13.00') CV	15163.8 (49.7500')	6477.0 (21.2500')	8686.8 (28.5000')	86528.6 (283.88')	1°41'31"	2° 54'00"	187924.4 (616.55')	1676.4 (5.5000')	2514.6 (8.2500')
8	7° 09'10"	3962.4 (13.00') CV	17805.4 (58.4167')	6223.0 (20.4167')	11582.4 (38.0000')	160992.3 (528.19')	1°41'31"	2° 54'00"	187924.4 (616.55')	1905.0 (6.2500')	2870.2 (9.4167')
8	7° 09'10"	5943.6 (19.50') CV	32031.2 (69.0000')	9448.8 (31.0000')	11582.4 (38.0000')	146941.0 (482.09')	1°04'24"	1°59'15"	372517.4 (1222.17')	1905.0 (6.2500')	2870.2 (9.4167')
10	5° 43'29"	5943.6 (19.50') CV	24053.8 (78.9167')	9575.8 (31.4167')	14478.0 (47.5000')	245696.2 (806.09')	1°04'24"	1°59'15"	372517.4 (1222.17')	2260.6 (7.4167')	3454.2 (11.3333')

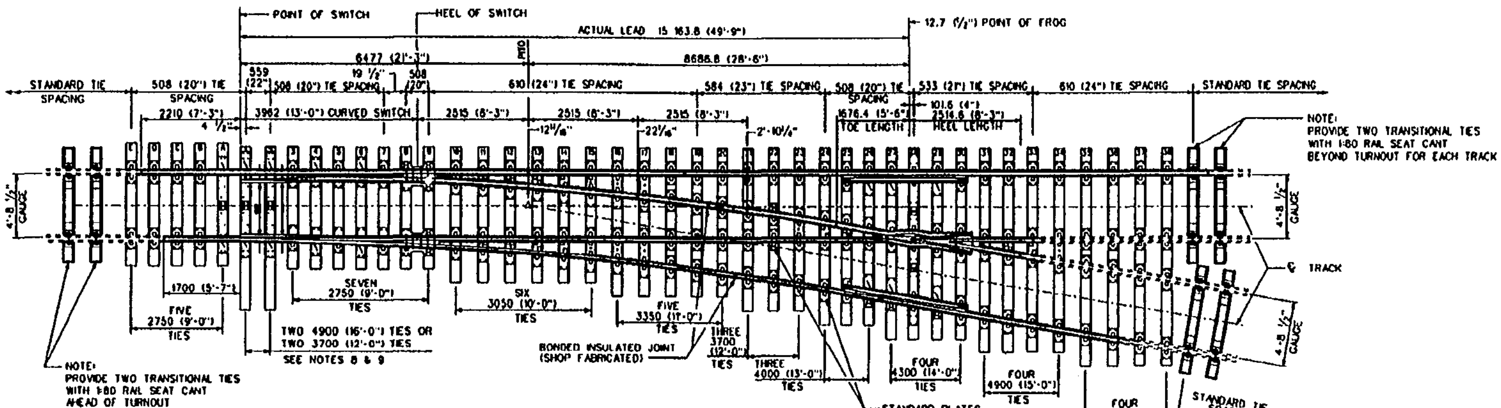
CROSSOVER DATA TABLE - BALLASTED OR DIRECT FIXATION TRACK							
TRACK CENTERS T	TURNOUT NUMBER	SWITCH LENGTH AND TYPE	OVERALL LENGTH Z	CROSSING DATA		OTHER DATA	
				K	M	D	G
3962.4 (13.00')	6	3962.4 (13.00') CV	36563.4 (119.9588')	19°03'16"	8670.4 (28.4464')	18281.7 (59.9794')	-1217.3 (-3.9938')
4267.2 (14.00')	6	3962.4 (13.00') CV	38379.5 (125.9172')	19°03'16"	8670.4 (28.4464')	19189.8 (62.9586')	-309.2 (-1.0146')
3962.4 (13.00')	8	5943.6 (19.50') CV	50472.5 (165.5922')	14° 18'20"	11525.4 (37.8132')	25236.2 (82.7961')	-1557.7 (-5.1105')
4267.2 (14.00')	8	5943.6 (19.50') CV	52903.5 (173.5608')	14° 18'20"	11525.4 (37.8132')	26450.7 (86.7804')	-304.8 (-1.1262')
4572.0 (15.00')	8	5943.6 (19.50') CV	55330.1 (181.5294')	14° 18'20"	11525.4 (37.8132')	27665.1 (90.7647')	-871.1 (-2.8581')
3962.4 (13.00')	10	5943.6 (19.50') CV	58677.1 (192.5104')	11° 26'58"	14387.1 (47.2018')	29338.6 (96.2552')	-1908.8 (-6.2624')
4267.2 (14.00')	10	5943.6 (19.50') CV	61717.6 (202.4856')	11° 26'58"	14387.1 (47.2018')	30858.8 (101.2428')	-388.5 (-1.2748')

DATA FOR 3962 (13.00') TRACK CENTERS ARE SHOWN FOR INFORMATION ONLY. SEE NOTE 4.

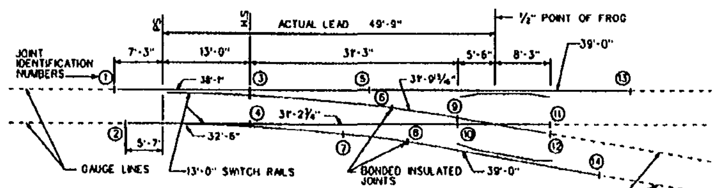
NOTES:

1. GEOMETRIC DISTANCES BASED ON 1435 (4'-8½") GAUGE. GEOMETRIC DISTANCES BASED ON TANGENT PITO TO PITO. TURNOUTS ARE BASED ON AREA "M" PLAN NO. 920-51 AND CROSSINGS ARE BASED ON AREA "M" PLAN NO. 769-80 AND 761-83.
2. ALL DATA EXCEPT "G", "K" AND "M" ALSO APPLY TO SINGLE CROSSOVERS.
3. ALL SINGLE CROSSOVERS CONNECTING TRACKS WITH CENTERS EQUAL TO OR GREATER THAN 15'-0", SHALL BE DESIGNED AS TWO TURNOUTS WITH A TANGENT TRACK CONNECTION BETWEEN THE TURNOUTS.
4. DOUBLE CROSSOVERS AT LESS THAN 4267 (14'-0") TRACK CENTERS SHOULD NOT BE USED, AS THEY REQUIRE SPECIAL MODIFICATIONS AS FOLLOWS:
   a. DOUBLE CROSSOVERS AT 4115 (13'-6") CENTERS REQUIRE SELF GUARDED FROGS (AREA PLAN NO. 641-82) AS THEY ARE IMPOSSIBLE TO GUARD WITH STANDARD GUARD RAILS.
   b. DOUBLE CROSSOVERS AT TRACK CENTERS OF 3962 (13'-0") OR LESS REQUIRE REVISIONS TO STANDARD TURNOUT GEOMETRY.

Figure 6.4.1 Turnout and Crossover Data and Arrangement



NO. 6 TURNOUT BALLASTED WITH TIMBER TIES
SCALE: ¼" = 1'-0"



RAIL LAYOUT DIAGRAM
SCALE: ⅛" = 1'-0"

TURNOUT DATA			
FROG		NUMBER	6
		ANGLE	9°31'38"
		TOE LENGTH	1676.4 (5'-6")
		HEEL LENGTH	2514.6 (8'-3")
		TOTAL LENGTH	13'-9"
		TOE SPREAD	10 ¹¹⁄₃₂"
		HEEL SPREAD	16 ¹¹⁄₁₆"
SWITCH		LENGTH OF SWITCH RAIL	13'-0"
		HEEL SPREAD	6 ¼"
		HEEL ANGLE	2°54'00"
	CURVED POINT	THICKNESS AT POINT	0"
		ANGLE AT POINT	1°41'31"
		RADIUS	616.55'
		VERTEX DISTANCE	0"
	STRAIGHT POINT	THICKNESS AT POINT	0"
		ANGLE AT POINT	1°41'31"
		RADIUS	611.84'
		VERTEX DISTANCE	0"
ACTUAL LEAD			49'-9"
STRAIGHT CLOSURE RAIL DISTANCE			31'-3"
CURVED CLOSURE RAIL DISTANCE			31'-10¾"
TURNOUT CURVE		CENTER LINE RADIUS	283.88'
		DEGREE OF CURVE	20°10'59"
		CENTRAL ANGLE	6°37'38"
TANGENT ADJACENT TOE OF FROG			= 18¹¹⁄₁₆"

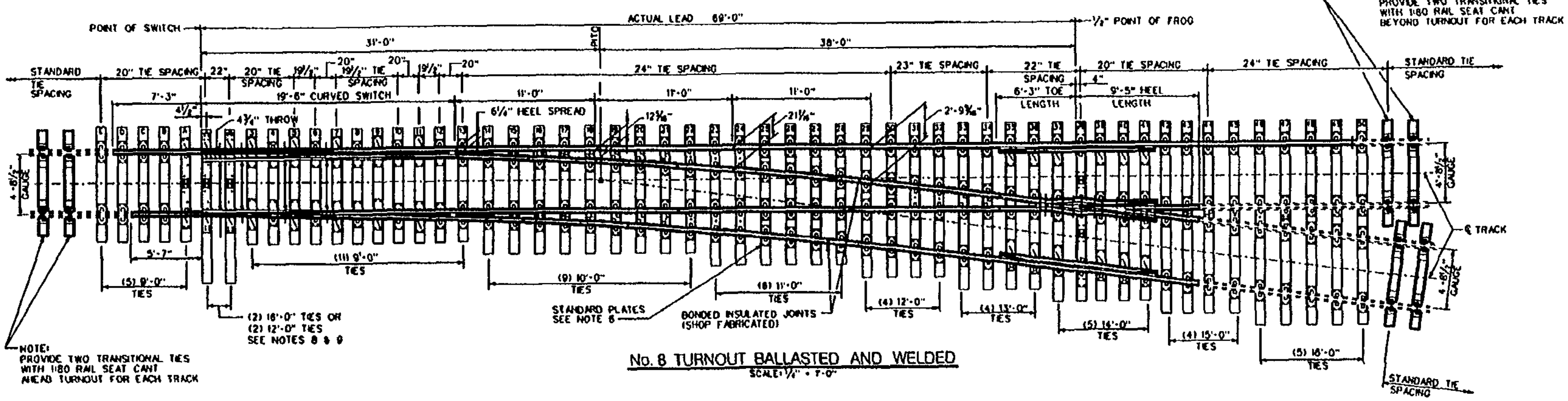
NO. 6 BALLASTED TURNOUT BILL OF MATERIAL	
QTY.	DESCRIPTION
1 ASSY.	13'-0" INSULATED CURVED SWITCH COMPLETE
1 ASSY.	NO. 6 RAIL BOUND MANGANESE FROG WITH PLATES
2 ASSY	12'-3" U69 GUARD RAIL WITH PLATES
1 EACH	CLOSURE RAILS WITH BONDED INSULATED JOINTS 31'-9¼" AND 39'-0"
1 EACH	CLOSURE RAIL 31'-2¼" AND 39'-0"
1 SET	TIMBER SWITCH TIES AS LISTED (SEE NOTE 8)
56	STANDARD PANDROL TIE PLATES FOR "e" CLIPS (SEE NOTE 6)
12	36" AREA JOINT BARS WITH BOLTS, NUT & WASHERS (SEE NOTE 10)
109	HIGH DENSITY POLYETHYLENE PADS (VARIOUS SIZES) MAY BE RQUIRED
472	LAG SCREW ASSEMBLIES INSULATED MAY BE REQUIRED
246	PANDROL NO. 2055 "e" CLIPS, INCLUDING MODIFIED 'e' CLIPS AT JOINT BARS

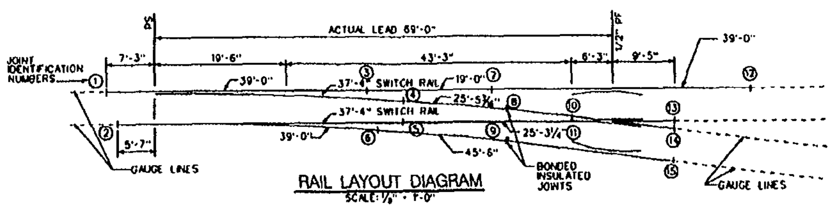
BILL OF MATERIAL TIMBER SWITCH TIES 180 x 230 (7"x9")	
LENGTH	QTY.
2750 (9'-0")	12
3050 (10'-0")	6
3350 (11'-0")	5
3700 (12'-0") +	3 (OR 5) SEE NOTES 8 & 9
4000 (13'-0")	4
4300 (14'-0")	4
4600 (15'-0")	4
4900 (16'-0")	4 (OR 6) SEE NOTE 8
TOTAL	43

NOTES:

1. LEFT HAND TURNOUT SHALL BE OPPOSITE TO THAT SHOWN.
2. RAIL AND COMPONENTS CONFORM TO THE 115 RE RAIL SECTION.
3. ALL RAILS INDICATED BY SOLID LINES IN RAIL LAYOUT DIAGRAM ARE HIGH STRENGTH RAIL.
4. DASHED LINES IN RAIL LAYOUT DIAGRAM INDICATE STANDARD CONTROL COOLED RAIL BEYOND TURNOUT RAIL. RAIL INDICATED BY DASHED LINES ARE NOT INCLUDED IN THE BILL OF MATERIAL ON THIS DWG.
5. CLOSURE RAIL LENGTHS ALLOW ⅛ INCH FOR EACH BOLTED JOINT. BOLTED JOINT SHALL CONFORM TO THE FOLLOWING:
   a. RAIL END DRILLING SHALL BE IN ACCORDANCE WITH AREA MANUAL FOR 36" SIX HOLE JOINT BARS FOR BOLTED TRACK.
   b. RAIL ENDS FOR BOLTED TRACK JOINTS SHALL BE BEVELED IN ACCORDANCE WITH AREA PLAN No. 1005-40.
6. STANDARD PLATES SHALL BE FURNISHED FOR ALL TIES WHERE SPECIAL PLATES ARE NOT REQUIRED. INSULATION MAY BE REQUIRED.
7. ALL SPECIAL TRACKWORK TURNOUT PLATES MAY REQUIRE INSULATION.
8. TWO ADDITIONAL TIES REQUIRED FOR:
   - HAND THROW SWITCH-TWO 16'-0"
   - POWER OPERATED SWITCH-TWO 12'-0"
9. HEADBLOCK TIES FOR POWER SWITCH MACHINE SHALL BE 9"x9" IN SECTION AND SHALL BE DAPPED AS REQUIRED FOR SWITCH MACHINE.
10. JOINT BARS SHALL ALLOW MODIFIED RAIL FASTENING CLIP TO SECURE RAIL BASE.

Figure 6.4.2 Number 6 Turnout—Ballasted Timber Ties with 13' Curved Switch Points





TURNOUT DATA			
FROG		NUMBER	8
		ANGLE	7°09'10"
		TOE LENGTH	6'-3"
		HEEL LENGTH	9'-5"
		TOTAL LENGTH	15'-8"
		TOE SPREAD	8¾"
		HEEL SPREAD	14 11/32"
SWITCH		LENGTH OF SWITCH	19'-6"
		HEEL SPREAD	6 1/4"
		HEEL ANGLE	1°59'15"
	CURVED POINT	THICKNESS AT POINT	0"
		ANGLE AT POINT	1°04'24"
		SWITCH RAIL RADIUS	1222.17'
		VERTEX DISTANCE	0"
	STRAIGHT POINT	THICKNESS AT POINT	0"
		ANGLE AT POINT	1°04'24"
		STOCK RAIL RADIUS	1217.46'
		VERTEX DISTANCE	0"
ACTUAL LEAD			69'-0"
STRAIGHT CLOSURE RAIL DISTANCE			43'-3"
CURVED CLOSURE RAIL DISTANCE			43'-5 3/8"
TURNOUT CURVE		CENTER LINE RADIUS	482.09'
		DEGREE OF CURVE	11°53'05"
		CENTRAL ANGLE	5°09'55"
TANGENT ADJACENT TOE OF FROG			-0 1/8"

No. 8 BALLASTED TURNOUT

BILL OF MATERIAL

QTY.	DESCRIPTION
1 ASSY.	19'-6" INSULATED CURVED SWITCH COMPLETE
1 ASSY.	NO. 8 RAILBOUND MANGANESE FROG WITH PLATES
2 ASSY	12'-6" U69 GUARD RAIL WITH PLATES
1 EACH	CLOSURE RAILS WITH BONDED INSULATED JOINTS 25'-5 3/16" AND 45'-6"
1 EACH	CLOSURE RAIL 25'-3 1/4", 19'-0" AND 39'-0"
1 SET	TIMBER SWITCH TIES AS LISTED (SEE NOTE 8)
70	STANDARD PANDROL TIE PLATES FOR "e" CLIPS (SEE NOTE 6).
13	THERMITE WELDS
143	HIGH DENSITY POLYETHYLENE PADS (VARIOUS SIZES) MAY BE REQUIRED
602	LAG SCREW ASSEMBLIES INSULATED MAY BE REQUIRED
300	PANDROL NO. 2055 'e' CLIPS, INCL. MODIFIED 'e' CLIPS FOR I.J.

BILL OF MATERIAL

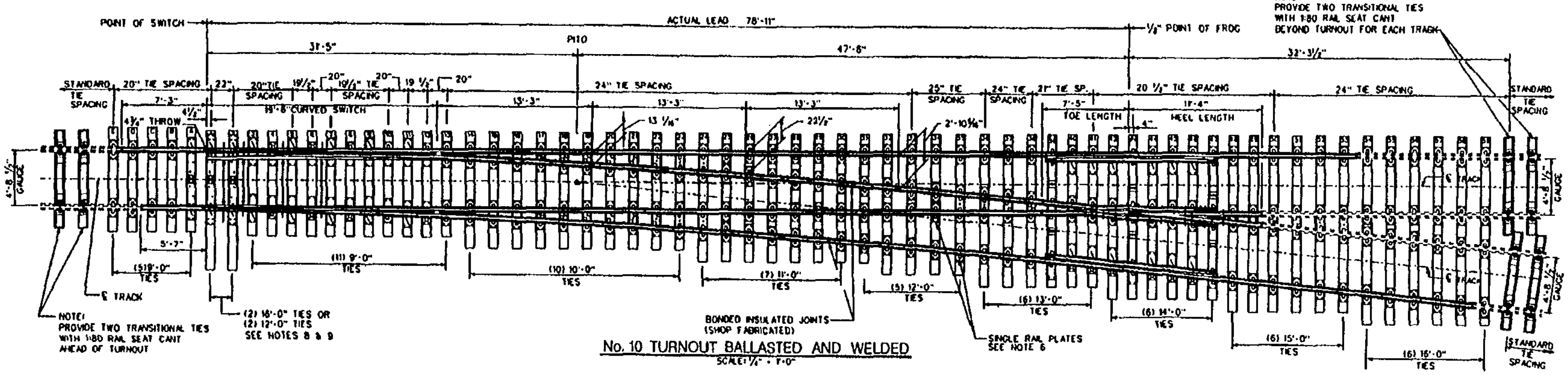
TIMBER SWITCH TIES (7"x9")

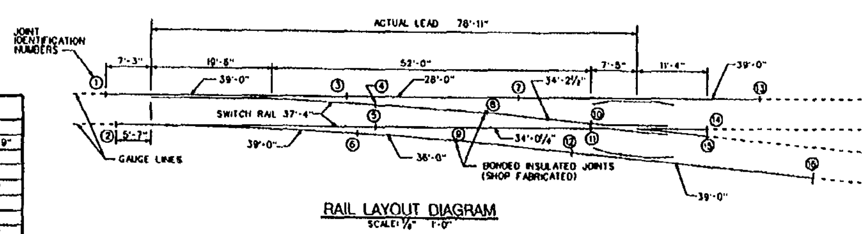
LENGTH	QTY.
9'-0"	16
10'-0"	9
11'-0"	6
12'-0" •	4 (OR 6) SEE NOTES 8 & 9
13'-0"	4
14'-0"	5
15'-0"	4
16'-0"	5 (OR 7) SEE NOTE 8
TOTAL	55

NOTES:

1. LEFT HAND TURNOUT SHALL BE OPPOSITE TO THAT SHOWN.
2. RAIL AND COMPONENTS CONFORM TO THE 115 RE RAIL SECTION.
3. ALL RAILS INDICATED BY SOLID LINES IN RAIL LAYOUT DIAGRAM ARE HIGH STRENGTH RAIL.
4. DASHED LINES IN RAIL LAYOUT DIAGRAM INDICATE CONTINUOUS WELDED RAIL (STD. OR HEAT TREATED) BEYOND TURNOUT RAIL. RAIL INDICATED BY DASHED LINES ARE NOT INCLUDED IN THE BILL OF MATERIAL ON THIS DRAWING.
5. CLOSURE RAIL LENGTHS ALLOW 1/8" FOR EACH THERMITE WELD.
6. STANDARD PLATES SHALL BE FURNISHED FOR ALL TIES WHERE SPECIAL PLATES ARE NOT REQUIRED. INSULATION MAY BE REQUIRED.
7. ALL SPECIAL TRACKWORK TURNOUT PLATES MAY REQUIRE INSULATION.
8. TWO ADDITIONAL TIES REQUIRED FOR:
   - HAND THROW SWITCH-TWO 16'-0"
   - POWER OPERATED SWITCH-TWO 12'-0"
9. HEADBLOCK TIES FOR POWER SWITCH MACHINE SHALL BE 9"x9" IN SECTION AND SHALL BE DAPPED AS REQUIRED FOR SWITCH MACHINE.

Figure 6.4.3 Number 8 Turnout—Ballasted Timber Ties with 19'-6" Curved Switch Points





TURNOUT DATA			
FROG	NUMBER		10
	ANGLE		5°43'29"
	TOE LENGTH		7'-5"
	HEEL LENGTH		11'-4"
	TOTAL LENGTH		18'-9"
	TOE SPREAD		8½"
	HEEL SPREAD		14⅛"
SWITCH	LENGTH OF SWITCH		19'-6"
	HEEL SPREAD		6¼"
	HEEL ANGLE		1°59'15"
	CURVED POINT	THICKNESS AT POINT	0"
		ANGLE AT POINT	1°04'24"
		SWITCH RAIL RADIUS	1222.17'
		VERTEX DISTANCE	0"
	STRAIGHT POINT	THICKNESS AT POINT	0"
		ANGLE AT POINT	1°04'24"
		STOCK RAIL RADIUS	1217.46'
		VERTEX DISTANCE	0"
ACTUAL LEAD			78'-11"
STRAIGHT CLOSURE RAIL DISTANCE			52'-0"
CURVED CLOSURE RAIL DISTANCE			52'-2"
TURNOUT CURVE	CENTER LINE RADIUS		806.09'
	DEGREE OF CURVE		7°06'45"
	CENTRAL ANGLE		3°44'14"
TANGENT ADJACENT TOE OF FROG			-8¹¹⁄₁₆"

NO. 10 BALLASTED TURNOUT

BILL OF MATERIAL

QTY.	DESCRIPTION
1 ASSY.	19'-6" INSULATED CURVED SWITCH COMPLETE
1 ASSY.	NO. 10 RAIL BOUND MANGANESE FROG COMPLETE
2 ASSY.	14'-6" GUARD RAIL WITH PLATES & ADJ. RAIL BRACES.
1 EACH	CLOSURE RAILS WITH BONDED INSULATED JOINTS 34'-2½" AND 36'-0"
1 EACH	CLOSURE RAILS 28'-0", 34'-0¼", 39'-0", 39'-0"
1 SET	TIMBER SWITCH TIES AS LISTED (SEE NOTE 8)
90	SINGLE RAIL TIE PLATES FOR PANDROL "e" CLIPS (SEE NOTE 6).
14	THERMITE WELDS
170	HIGH DENSITY POLYETHYLENE PADS (VARIOUS SIZES) MAY BE REQUIRED
728	LAG SCREW ASSEMBLIES INSULATED MAY BE REQUIRED
368	PANDROL NO. 2055 'e' CLIPS INCL. MODIFIED 'e' CLIPS FOR I.J.

BILL OF MATERIAL

TIMBER SWITCH TIES (7"x9")

LENGTH	QTY.
9'-0"	16
10'-0"	10
11'-0"	7
12'-0"	5 (OR 7) SEE NOTES 8 & 9
13'-0"	8
14'-0"	6
15'-0"	6
16'-0"	6 (OR 8) SEE NOTE 8
TOTAL	64

NOTES:

1. LEFT HAND TURNOUT SHALL BE OPPOSITE TO THAT SHOWN.
2. RAIL AND COMPONENTS CONFORM TO THE 115 RE RAIL SECTION.
3. ALL RAILS INDICATED BY SOLID LINES IN RAIL LAYOUT DIAGRAM ARE HIGH STRENGTH RAIL.
4. DASHED LINES IN RAIL LAYOUT DIAGRAM INDICATE CONTINUOUS WELDED RAIL (STD OR HEAT TREATED) BEYOND TURNOUT RAIL. RAIL INDICATED BY DASHED LINES ARE NOT INCLUDED IN THE BILL OF MATERIAL ON THIS DRAWING.
5. CLOSURE RAIL LENGTHS ALLOW ⅛" FOR EACH THERMITE WELD.
6. SINGLE RAIL PLATES SHALL BE FURNISHED FOR ALL TIES WHERE SPECIAL PLATES ARE NOT REQUIRED. INSULATION MAY BE REQUIRED.
7. ALL SPECIAL TRACKWORK TURNOUT PLATES MAY REQUIRE INSULATION.
8. TWO ADDITIONAL TIES REQUIRED FOR:
   - HAND THROW SWITCH-TWO 16'-0"
     POWER OPERATED SWITCH-TWO 12'-0"
9. HEADBLOCK TIES FOR POWER SWITCH MACHINE SHALL BE 9"x9" IN SECTION AND SHALL BE DAPPED AS REQUIRED FOR SWITCH MACHINE.

Figure 6.4.4 Number 10 Turnout—Ballasted Timber Ties with 19'-6" Curved Switch Points

6.4.1 Diverging Speed Criteria

Turnout size (by either frog number or radius) should be selected to provide the highest diverging movement speed possible that is consistent with adjoining track geometry. A high speed turnout is not needed if the adjoining track geometry restricts operating speed. Similarly, a sharp turnout should generally not be used in a track segment that has no restrictions on operating speed. Limits on operating speeds through the curved side of turnouts are typically based on the turnout geometry and the maximum unbalanced superelevation criteria adopted for the system. In many cases, the closure rail zone will impose a greater restriction on operating speed than the switch, particularly if tangential switch geometry is not used. There are typically no operating speed restrictions on the straight through side of a turnout.

While larger number/radius turnouts will generally have higher initial costs, they will incur less wear and tear and can be more economical in the long run. There are reasonable limits to this rule of course—it makes little sense, for example, to install a Number 20 turnout that will never be traversed at more than 40 km/hr (25 mph). In general, trackwork designers will find that Number 8, 10 and possibly Number 15 turnouts will typically be the most economical choices for main line track on virtually any light rail system.

6.4.2 Turnout Size Selection Guidelines

The following criteria recommend various turnout sizes for various track applications. The typical conditions and operating speed objectives are based on a rule of thumb which states that the frog number should be about one-third of the desired diverging movement operating speed in kilometers per hour (one-half of the desired speed in miles per hour). Handbook users should keep in mind that operating speed objectives vary among light rail operations, as well as from one portion of an LRT system to another.

High speed on one system may be low speed on another. Accordingly, the recommendations that follow should be modified to suit on site-specific requirements.

- Route junctions between primary tracks should use No. 15 turnouts. A larger number turnout should be employed if the route geometry in proximity to the turnout does not restrict higher speed operations. When sufficient space is not available for a No. 15 turnout, or if there are nearby speed restrictions—such as station stops or roadway crossings—a sharper turnout, such as a No. 10, may be considered.
- Connections between primary main line tracks and slower speed yard and secondary tracks, including center pocket tracks, should typically use No. 10 turnouts. When design space for a No. 10 turnout is not available, a No. 8 turnout may be sufficient.
- Seldom-used crossover tracks that are provided for emergency and maintenance use only should use No. 8 turnouts. When sufficient design space for a No. 8 turnout is not available, a No. 6 turnout may be considered.
- Turnouts within maintenance facilities and storage yards should use either No. 8 or No. 6 turnouts. Main line connections to the maintenance facility and storage yard should use Number 10 turnouts
- Turnouts that are located in embedded track are often in odd geometric layouts and thus must be sized in accordance with the use and function of the turnout. Alternatives to the use of an embedded turnout should always be investigated

6.4.3 Sharp Frog Angle/Tight Radius Turnouts

Many light rail systems, particularly older street railway operations, use turnouts that are sharper than those suggested above. Frogs as low as number 5 and 4 are not uncommon. Many difficult alignment conditions may be resolved using turnouts that are curved through both the switch and the frog. Some transit agencies have curved frog turnouts with radii as sharp as 15 meters. In virtually all cases, these sharp turnouts were required due to unique site conditions and the particular requirements of the system. While such sharp turnouts are not recommended for general application, there is nothing inherently wrong with their use provided that they meet the requirements of the transit operation and the transit agency understands and accepts the limitations that sharp turnouts impose. Some of the restrictions imposed by sharp turnouts are:

- Vehicle fleet must be designed to be able to negotiate them. This may reduce the number of candidate light rail vehicles that can be considered for the system.
- Operations will be slower. Operating personnel must be made aware of the speed restrictions that the sharp turnouts impose and systems must be in place to limit speeds to the allowable limit. This can be a significant problem on a system, or portion of a system, where vehicle speed is entirely under the operator's control. Most vehicle storage yard tracks, which are the most likely location for sharp turnouts, do not have signal systems that provide speed control. This makes it highly probable that sharp turnouts will be negotiated at higher-than-design speeds, leading to excessive wear, more frequent maintenance, and an increased risk of derailments. A common problem in this regard, known as "cracking the whip," is a distressingly common operating practice on many systems where the LRV operator may docilely enter the turnout at the posted speed limit but then accelerate. The result is that the rear truck enters the curve and travels through the turnout at a much higher speed than intended. High rail and wheel wear will result and derailments of rear trucks and trucks on rear cars of multiple car trains are not uncommon.
- Maintenance expenses will be higher. Even if vehicle speed is controlled, either through the signal system or by strict enforcement of operating rules, sharp turnouts will incur more wear than flatter turnouts. If the associated maintenance expense is preferable to the additional first cost of a right-of-way that would permit the use of flatter turnouts, then sharp turnouts may be a prudent choice. If, on the other hand, a life-cycle cost analysis shows that procuring additional right-of-way that allows flatter turnouts will reduce the overall expense, then that course should be pursued.

6.4.4 Equilateral Turnouts

Equilateral turnouts split the frog angle in half between both sides of the turnout, thereby producing two lateral diverging routes. Both sides of the turnout are curved. Equilateral turnouts are occasionally suggested for the end of double-track locations and for locations where a turnout must be installed on a curve. The track designer should consider the following characteristics:

- A perfectly symmetrical equilateral turnout will evenly divide not only the frog angle but also the switch angle. The division of the switch angle will require a custom set of stock rails, each with half the normal stock rail bend. This is the preferred arrangement when both hands are used in the facing point direction, such as the diverging turnout at a route junction.

- An alternative to customized stock rails is to configure the switch in an ordinary lateral turnout, thereby giving one movement the straight route through the switch and the other movement the lateral route. The frog does not need to be oriented symmetrically and the optimum alignment for each route may be achieved by rotating it by an amount equal to the switch angle. This switch and frog orientation would be a preferred arrangement for an end of double-track location where extension of the double track is not expected to occur in the near future.
- If the switch angle is to be split equally, curved switch points will need to be specially designed and fabricated since each point must not only have a concave curve on its gauge face, but also a concave vertical surface on its back face. Such points are not off-the-shelf items and the transit system will have to procure spare points for future replacement. Straight switch points on the other hand, such as the AREMA 5029-millimeter (16.5-foot) design, can be obtained off-the-shelf although they still must be matched to custom stock rails. If the switch is oriented as in an ordinary lateral turnout, standard switch point rails can be used.
- The lead distance of the equilateral turnout need not have any direct correlation to the customary lead for a lateral turnout. The closure curves between the switch and frog can be configured to any geometry that is suitable to meet the speed objectives of the turnout.

The use of an equilateral turnout on a curve usually does not provide satisfactory ride quality and is, therefore, not recommended.

6.4.5 Curved Frog

A straight frog is standard for most turnouts, for both normal and diverging train movements. This creates a "broken back curve" alignment for the diverging movement that can provide a disagreeable ride quality, particularly in lower numbered (sharp radius) turnouts. If a system will have a large number of lower numbered turnouts, such as for yard tracks, and there are approximately equal quantities of right-hand and left-hand turnouts, it may be beneficial to consider curved frogs that allow a uniform turnout curve. A superior yard layout may be possible using curved frog turnouts, as shown in **Figure 6.4.5**, without incurring excessive costs.

6.4.6 Slip Switches and Lapped Turnouts

Slip switches and lapped turnouts are often suggested as a means of concentrating a large number of train movements into a constrained site. Such components are very expensive to procure and maintain and are seldom justifiable in a life-cycle cost analysis. They should only be considered in cases where extremely restrictive rights-of-way leave no other design options.

6.4.7 Track Crossings

Whenever possible, track crossings (diamonds) should have angles that do not require movable point design. Movable point crossings have high initial costs and require more frequent maintenance and, therefore, should be used only as a last resort. To provide for the use of rigid crossings only, the route geometry engineer will be required to configure the tracks so that crossing tracks intersect at an angle at least equal to that of a No. 6 frog (9°31'38"). Some systems have successfully used crossings with flatter angles, but they are not recommended because of the increased potential of derailment at the unguarded center frog points. If a flat-angle movable point crossing appears to be required at a location such as a route junction, a detailed investigation of alternatives should be conducted before trackwork final design commences. These alternatives could include spreading track centers to permit one track to cross the other at a sharper angle or substituting a crossover track in advance of the junction for the crossing diamond. Simulations may be required to determine if the operational scenarios resulting from an alternative track plan are acceptable. The maintenance requirements of the baseline movable point crossing should be included in the analysis, including the operational restrictions that may be enforced during such maintenance.

6.5 SWITCH DESIGN

The switch area is the most critical portion of any turnout. Most turnout maintenance is switch related, requiring both trackwork and signal maintenance. Most derailments occur at and are caused by unmaintained or neglected switches. As such, they are one of the most important locations to examine for the interaction between the wheel and the rail. As a guideline, the following sections will discuss the various types of switch designs that can be used on light rail systems, and will provide guidelines to follow in selecting what design to implement.

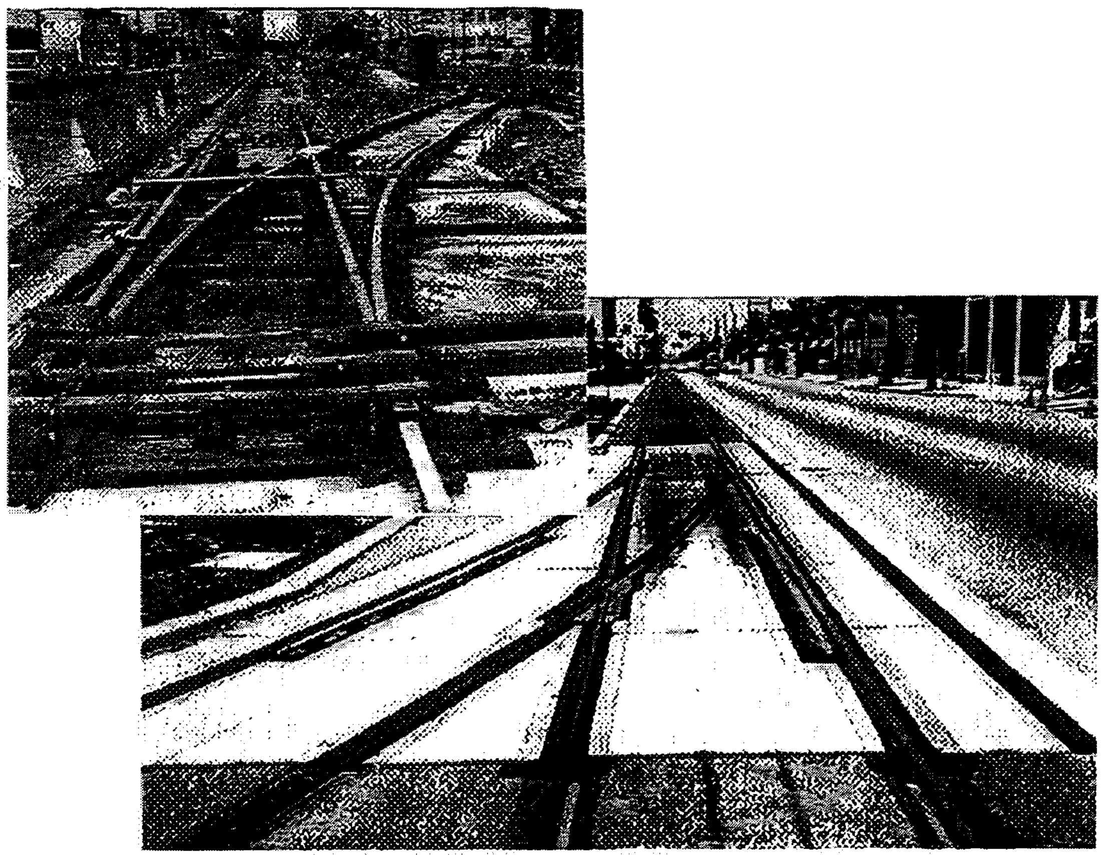
6.5.1 Conventional Tee Rail Split Switches

Most rail transit systems in North America use switch point rails that are identical or similar to designs used by North American freight railroads. Such switches, known as split switches, generally conform to designs promulgated by the American Railway Engineering & Maintenance-of-Way Association (AREMA). Split switches are produced by planing and bending a piece of standard tee rail to a knife edge point on one end. The sharpened point then lays up against a section of standard rail and diverts the flanged wheel from one track to another. Split switches are relatively inexpensive to produce and provide satisfactory service under most operating scenarios.

Split switch point rails can be either straight or curved. Straight switch point rails can be used universally within a turnout, but are almost always an inferior choice for a diverging route. As a guideline, curved switch point rails are recommended for all transit designs to provide a much smoother transition through a turnout.

6.5.2 Tangential Geometry Switches

Conventional North American curved switch points still require the wheels to make a somewhat abrupt change of direction near the point of switch. The actual angle at the point rail will vary depending on the length from the switch point to the heel of switch, but it typically ranges between 1 and 3 degrees. Depending on the speed of the transit vehicle, this change in direction can produce an uncomfortable ride. In addition, a switch point used for diverging movement will frequently incur a much greater amount of wear due to the abrasive impact associated with redirecting the vehicle wheels.



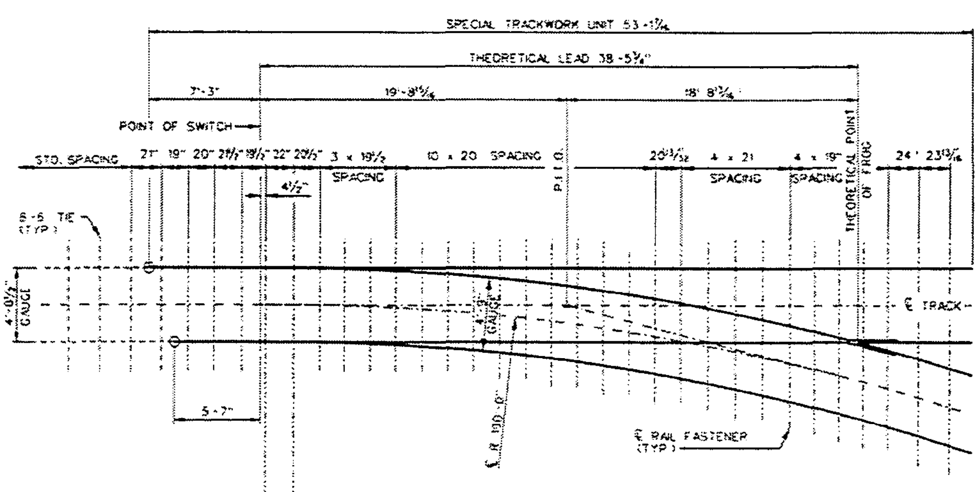


Figure 6.4.5 Typical Curved Frog Turnout

To improve switch performance and service life, European track designers developed "tangential geometry" switches. In a tangential geometry switch, the switch point that deflects the diverging movement is not only curved but also oriented so that the curve is tangential to the main track The wheel is not required to make an abrupt change of direction; instead it encounters a flatter circular curve that gradually redirects the wheel. The lead distance for a tangential geometry turnout is typically much longer than for an ordinary turnout with the same frog number

European tangential geometry switch point rails are usually manufactured from special rolled rail sections that are not symmetrical about their vertical axes. These asymmetrical switch point rail sections are also usually shorter in height than switch stock rails, thereby permitting the switch slide plate to anchor the stock rail to resist rollover. The difference in rail configuration and height usually requires a shop-forged connection between the asymmetrical switch point rail and the common tee rail used in the turnout closure curve. The Zu 1-60 section (**Figure 6.5.1**) is a typical asymmetrical point rail section. Nearly all tangential design switches also employ a floating heel design.

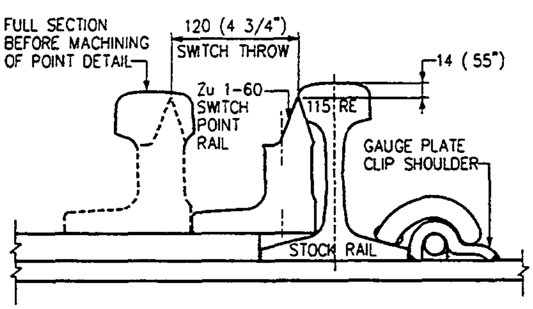


Figure 6.5.1 Zu1-60 Rail Section for Switch Point

Tangential geometry turnouts should be considered whenever high speeds or a large number of movements must be made through the diverging side of a turnout. A few North American manufacturers are now producing proprietary tangential geometry switch point rail designs. These may be appropriate for some applications on a light rail transit system but are not generally warranted.

6.5.3 Uniform and Graduated Risers

Split switch designs, whether using conventional AREMA geometry or tangential alignment, typically elevate the top of the switch point rail approximately 6 millimeters (1/4 inch) above the top of the stock rail. This prevents false flanges on worn wheels from contacting the top of the stock rail and possibly lifting the wheel off the top of the switch rail. To achieve this elevation, special riser switch plates are incorporated beneath the switch rails. This additional elevation can be eliminated once the switch rail has diverged sufficiently from the stock rail such that false flanges on wheels are no longer a concern. The two design details that achieve this transition are called uniform risers and graduated risers.

A uniform riser switch maintains the additional 6 millimeters of height through the heel block of the switch and then ramps it out over a distance of 4 to 5 switch ties beyond the heel. At each of these ties, a special rail fastening plate must be installed that provides progressively less riser elevation until the base of the closure rails beyond the switch are in the same plane as the stock rails. Such turnout plates must be specially fabricated and each will fit in only one location within the turnout.

A graduated riser switch maintains the additional elevation only as long as absolutely necessary and then ramps it out prior to the heel block of the switch. Two vertical bends are required in the switch rail—one concave and the next convex—so that the 6 millimeters of riser elevation is eliminated in increments of 2 or 3 millimeters. Special plates are not required beyond the switch heel block; most timber tie ballasted track turnouts with graduated risers use hook-twin tie plates in that area.

As a guideline, uniform risers will usually provide the best and most economical service for turnouts in main track or where insulation is required. Uniformity of maintenance suggests that switches in yard and secondary tracks on the same transit system should also use uniform risers. Graduated risers should only be considered for use in maintenance and storage yard tracks—areas where special plates for stray current isolation are typically not required.

European switch point design does not consider the raised switch point concept. Therefore, the selection of either uniform or graduated risers is not a concern. However, both raised switch point and level switch point design perform best during operation with the regular maintenance of wheel truing. This will eliminate the false flange and secondary batter caused by the false flange. The standards for vehicle wheel maintenance plays an important part in the switch point design and must be considered when contemplating the interface between the wheel and switch point.

6.5.4 Switches for Embedded Track

Turnouts in embedded track are a signature characteristic of light rail transit systems. Whenever the railroad or rail transit track must be paved or embedded to permit either rubber-tired vehicles or pedestrians to travel along or across the track area, conventional ballasted track split switches—either conventional or tangential design—are impractical. The switch point "throw," the distance the switch point rail needs to move from one orientation to another, results in an unacceptably large void in the pavement surface. This void is dangerous to roadway vehicles and pedestrians. Voids also tend to collect debris and dirt, which impair switch operations. To deal with these difficulties, trackwork designers long ago developed what are known as tongue switches.

A tongue switch consists of a housing that incorporates the three rails that converge at any switch The switch tongue is usually located in a roughly triangular opening in the center of the housing . The switch tongue is typically grooved on its top surface and either pivots or flexes on its heel end. This movement directs the wheel flange to either the straight track or the diverging track.

Tongue switches can either be used in pairs (a "double-tongue" switch) or a single tongue switch can be paired with a "mate." A mate is a rigid assembly that has no moving parts but rather only two intersecting flangeways in the top surface. The mate does not steer the wheels, it only provides a path for the wheel flange. All guidance must therefore come from the companion tongue switch. Traditional North American street railway operations used tongue switches and mates almost exclusively until very recently.

In a street environment, tongue switches are far easier to keep clean than conventional tee rail split switches. The mate component, having no moving parts, is especially well suited to a street environment; since the flangeways are no deeper than those in the adjoining track and are thus easy to keep clean.

6.5.4.1 North American Tongue Switch Designs

North American tongue switches are typically constructed of solid manganese steel and are designed as illustrated in the 980 series of drawings in the AREMA *Portfolio of Trackwork Plans* Those drawings show both double-tongue switches and a tongue switch/mate design. While these examples are conveniently available, a detailed examination is required to appreciate the differences between the AREMA designs and the configurations used by traditional street railway operations. **Figure 6.5.2** illustrates a typical tongue switch designed in accordance with the practices of the former American Transit Engineering Association (ATEA). These design differences include the following:

Figure 6.5.2 Tongue Switch and Mate—Non-embedded 149 RE 7A Rail

- Traditional street railways (transit systems) in North America typically employed tongue switches and mates rather than double-tongue switches which were more common for railroad service. This was probably due to a desire to reduce the number of moving parts to be maintained, a key factor on large streetcar systems that could have hundreds of switches in embedded track.
- Tongue switch and mate designs for street railway service, as well as modern flexible double-tongue switches, are typically curved throughout their length, with the point of the tongue recessed into the switch housing. The nearly tangential geometry results in turnout lead distances much shorter than straight tongue switches. Tongues with radii as short as about 15 meters (50 feet) were not uncommon.
- The flangeway widths in traditional street railway tongue switches and mates were narrower than those for railroad service. Track gauge was also usually unchanged from tangent track. The AREMA designs, on the other hand, have extremely wide flangeways and widened track gauge to accommodate steam locomotives with multiple axles and large diameter driving wheels. These factors make railroad tongue switch designs ill-suited for light rail vehicles that have narrower wheel treads and almost always have small wheel diameters. The wide flangeways are also hazardous to pedestrians.

Typically, the switch tongue is placed on the inside rail leading to the diverging curve, so that truck steering action is provided by the interaction between the back side of the wheel flange and the tongue This produces reliable steering of the truck due to the curve being continuously guarded. Some tongue switch designs amplified this guarding by depressing the wheel tread level of the diverging movement immediately beyond the point of switch, as shown in **Figure 6.5.3**. This causes the tongue to become an even more effective guard because it is higher than the wheel tread.

Switch tongues require frequent maintenance to keep them clean and tight. Traffic riding on top of a rigid tongue tends to loosen and rattle it. For that reason, many properties positioned tongue switches on the outside of the curve for turnouts that were used either infrequently or only for converging movements. With the tongue positioned on the outside of the curve and the mate on the inside, straight through LRV wheel movements do not ride on the tongue, providing a quieter street environment. Note, however, that with the mate on the inside of the curve, outside tongue switch turnouts are not fully guarded. The deletion of a continuous guard through the critical switch area can result in derailments under some circumstances. Accordingly, outside tongue switches were typically not employed on switches with radii of less than about 30 meters (100 feet).

The AREMA switch tongue design pivots on an integral cylinder that is positioned beneath the heel of the tongue. This cylinder is held in place by wedges on either side that are tightened by large diameter bolts. These wedges tend to work loose as both they and the cylinder wear, causing the tongue to rattle and rock which leads to noise and accelerated wear. Tightening the wedges will only temporarily correct the problem and over-tightening can make the switch difficult to throw.

The ATEA standard tongue switch included a tongue heel design that could be locked down by lever action. American special trackwork fabricators produced several other proprietary heel designs. These alternative heel designs generally required less maintenance and performed better in street railway use than the AREMA designs, but may have been ill-suited to the heavy axle load demands of railroad service. Manufacturers of these alternative designs are no longer in the transit industry and the patents on their designs may have lapsed, placing them in the public arena.

Standard American-designed tongue switches and mates were typically fabricated from manganese steel castings, similar to the solid manganese steel frogs. Some alternative designs were partially fabricated from either girder or tee rail sections. Tongue switches and mates have always been expensive items

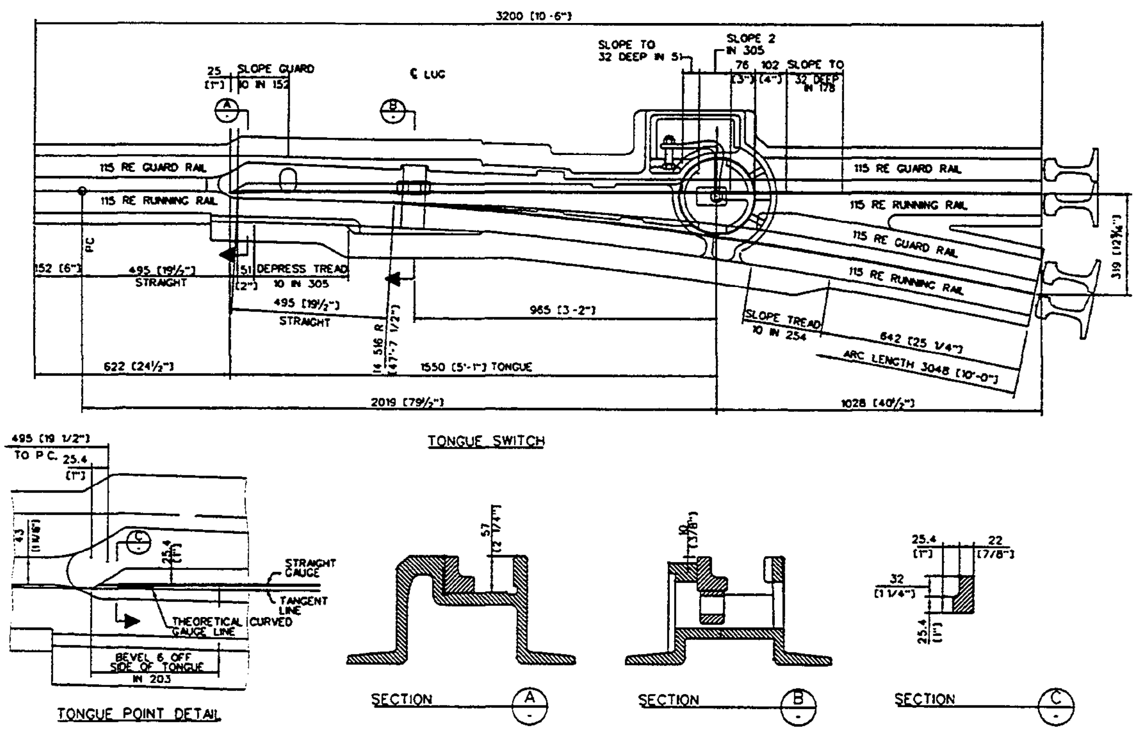


Figure 6.5.3 ATEA 75' Radius Solid Manganese Tongue Switch

because it is difficult to produce large castings to precise tolerances.

6.5.4.2 European Tongue Switch Designs

European light rail manufacturers developed flexible tongue switches in the post-WWII era. A typical flexible tongue switch is illustrated in **Figure 6.5.4**.

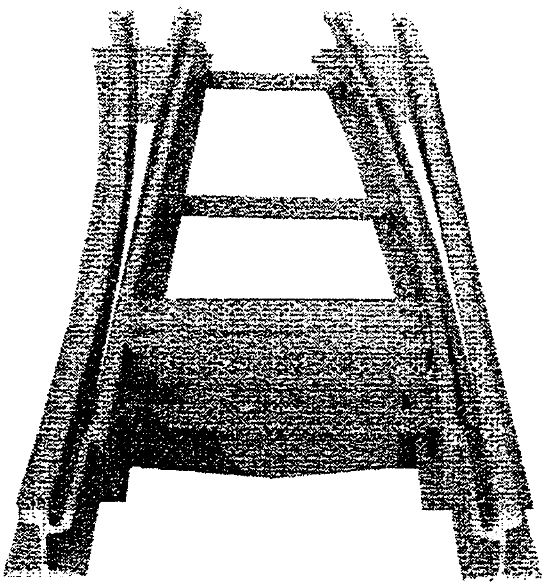


Figure 6.5.4 European Fabricated Steel Double Tongue Switch

Fabricated from rolled and machined rails and flat steel plate sections, these designs are considerably less expensive to manufacture than the solid manganese steel castings used in North American tongue switches and mates. The European design also typically employs double tongues (no mate) so that both wheels provide the steering action. Some European designs provide a rigid mate in lieu of an outside tongue switch, but usually only in complex layouts where overlapping turnouts make it impossible to provide the second tongue. In nearly all cases the tongues are rigidly fastened at the heel and flex, rather than pivot as is the case with North American design.

A number of North American light rail operators have procured such switches. In-track performance of these installations has varied. Traditional street railway operations rate fabricated flexible tongue switches as inferior to the robust design of the cast manganese steel tongue switches and mates, particularly with respect to wear. This poor performance could be due to the use of relatively soft European girder rail steels. Newer LRT operations, on the other hand, have no problems with the European designs, perhaps because they have no basis for comparison. Special surface hardening weld treatments can be incorporated in the design of flexible tongue switches to provide enhanced protection against wear. Refer to Section 5.2.4.

6.5.4.3 Switch Tongue Operation and Control

The switch throw of a tongue switch must be extremely short to preserve the switch tongue's ability to perform as an effective guard and to keep the open point flangeway as narrow as possible. The ATEA switch throw was only 64 millimeters (2-1/2 inches) long; a steel company designed an even shorter throw, 57 millimeters (2-1/4 inches). Such small switch throws are completely outside of the adjustment range of any standard railroad power switch machine of North American design. Instead, traditional North American street railway properties employed switch machines that are essentially a large solenoid. Depending on the current flow direction in the solenoid field, the switch will be thrown in one direction or another. Once thrown, the tongue is held in place by a spring loaded toggle. The toggle keeps the tongue in place until the solenoid is activated to throw the switch in the opposite direction. It also makes the switch trailable without having to first throw the switch. The most common design, which is still in production, was known as a Cheatham switch, after its original manufacturer. A major drawback of the solenoid design is that the spring toggle does not lock the switch tongue in place. This makes it possible for a switch tongue to accidentally throw under a rail car. Some North American operators have equipped Cheatham switches with point detection relays that verify electronically that the switch tongue has been completely thrown.

European suppliers have developed more modern switch machines for tongue switches that do provide point locking. Their design philosophy, however, does not comply with conventional North American signal practice.

6.5.4.4 Embedded Switch Drainage

Tongue switches, regardless of design, create an opening in the street surface that will inevitably fill with water and miscellaneous debris that is blown or washed into the switch. A positive drainage system must be installed that will also permit solid debris to be flushed away. The switch design should promote free drainage of any cavity and should also allow access into all cavities to enable cleaning out any solid material that may accumulate. Leaving such materials in place can interfere with the operation of the switch, promote corrosion, and facilitate stray currents. If the design includes cavities that are not essential to operation of the switch, but are likely to cause problems if they become filled with water or debris, the designers should consider filling such areas with a non-conductive material, such as an epoxy grout, prior to installation in track. The maintenance program should include sweeping, vacuuming, flushing, or blowing out embedded switches on an as-needed basis, as well as an inspection to verifiy that the drainage systems are clear and functional.

Corrosion of threaded fastenings in embedded switches can make them impossible to adjust. All threaded fastenings in embedded switches should be made of corrosion-resistant materials, such as bronze or stainless steel, to avoid corrosion problems.

6.5.4.5 Design Guidelines for Embedded Switches

If pedestrians can be reliably restricted from the location, embedded track switch designs identical to those used on open track turnouts can be considered, as shown in **Figure 6.5.5**, since conventional North American interlocked switch operating mechanisms can be used. If pedestrians cannot be reliably excluded from the vicinity of an embedded turnout—which is usually the case—embedded switches should use either traditional North American street railway tongue switches and mates or European fabricated flexible double-tongue switches. AREMA tongue switch and mate and double-tongue switch designs should not be used, as the flangeway openings are too large for areas where the general public has access.

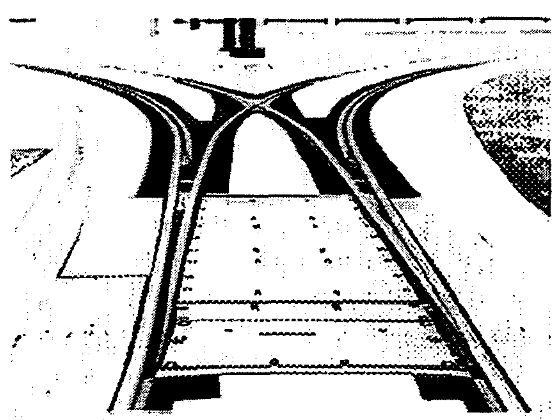


Figure 6.5.5 Embedded Tee Rail Switch—Equilateral Turnout, Steel Cover Plates, Epoxy Filler

6.5.5 Fully Guarded Tee Rail Switch Designs

Readers will have noted that tongue switch and mate turnouts provide a continuous restraining rail through the entire turnout. This includes the critical switch area, where the vehicle trucks must first make a change of direction. The preponderance of derailments occurs at switches. Providing a guard in the switch area can be very beneficial, particularly if the turnout curve immediately beyond the switch is sharp and protected with a restraining rail. Rail transit systems that have extremely sharp turnouts in open track often employ what are variously known as either "house top" or "cover guard" switches. These switch designs are the signature component of "fully guarded" turnouts. A typical house top double-point switch is illustrated in **Figures 6.5.6** and **Figure 6.5.7**. As the name implies, a fully guarded turnout is one in which the diverging movement through the turnout includes continuous guarding from ahead of the point of switch through the frog.

The switch area provides the unique characteristics of a fully guarded turnout, including:

- The house top guard piece, which is positioned above the straight switch point, protects the critical first 300 to 450 millimeters (12 to 18 inches) of the diverging switch point by pulling the wheel set away from it. Because the house top is rigidly fixed and must allow the passage of a wheel that is traveling on the straight switch rail, it does not provide any guarding action for lateral moves beyond the immediate vicinity of the point of the switch. The house top is usually a continuation of a conventionally designed restraining rail that is placed in the tangent track ahead of the switch point.

The "double point" for the straight switch rail provides a continuation of the restraining rail along the curved stock rail from the house top to the heel of the switch. This restraining rail is fastened directly to the back face of the switch point and extends the restraining face through the switch area beyond where the house top provides guarding action.

Note that the spread at the heel of the switch is much larger than in conventional AREMA split switch design. This is required so that the connection can be made between the double-point switch

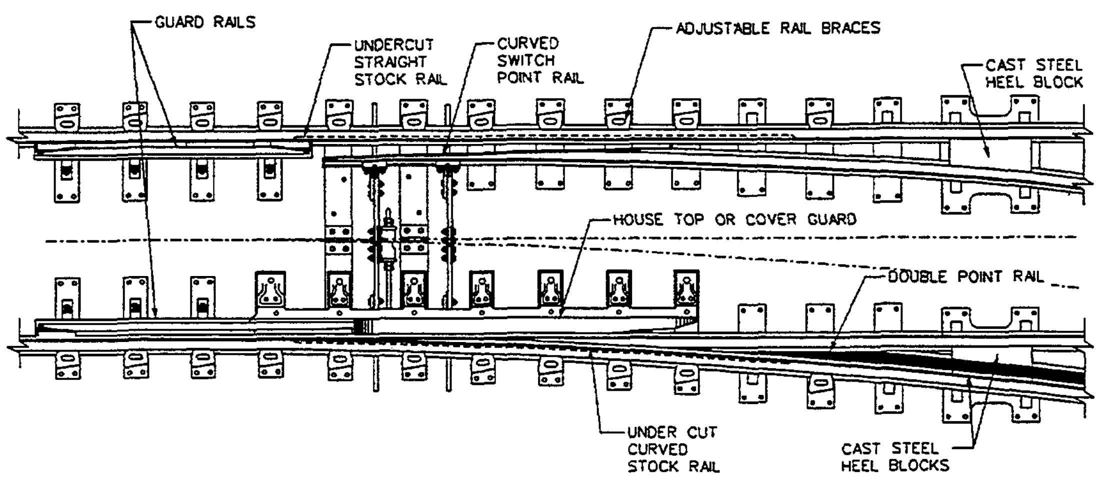


Figure 6.5.6 Fully Guarded House Top Switch

Figure 6.5.7 Fully Guarded Turnout—115 RE Rail Switch with House Top and Double Point Guarding

and the restraining rail. Some transit agencies have installed house tops without a double point, thereby protecting the point of the switch but not the remainder of the diverging switch rail.

In order for the double point to act as an effective restraining rail, the switch throw must be as short as possible. A throw distance no greater than 89 mm (3-1/2 inches) is required and a shorter throw dimension would be preferred. The normal throw distance for a powered switch in accordance with standard North American railroad practice is approximately 121 mm (4-3/4 inches). Most conventional North American power switch machine designs allow for an adjustment of 89 to 140 millimeters (3-1/2 to 5-1/2 inches). If they were set to the smaller dimension, they would have no adjustment left for wear. Hence, a power switch machine for a house top switch must be custom designed. North American signal equipment manufacturers can provide machines with short throws; however, the locking rod design cannot be as robust as those provided with ordinary switch machines. This makes them a high maintenance item that requires frequent adjustment.

A large amount of freeplay between wheel gauge and track gauge is essential for a house top to be an effective guard and to protect an appreciable portion of the curved switch rail. Therefore, house tops are most effective when used with railroad standard wheel gauges. If conventional transit standard wheel gauge is used as the standard on a light rail system, track gauge will need to be widened through the switch area.

Fully guarded turnouts with house top switches are rarely justified and should be used only as a last resort in cases where sufficient right-of-way cannot be acquired to permit the use of flatter turnouts.

6.5.6 Switch Point Detail

Very careful attention must be given to the cross section of the switch point rail at the point of the switch, particularly if the wheel contour is not a standard railroad design. If the transit system includes a street railway wheel profile with a narrow or short wheel flange (generally less than 25 millimeters (1 inch) in either dimension), there is a real danger that the wheel will either "pick" or ride up on the switch point. This is a particular problem in facing point diverging movements.

In general, the top of the tip of the switch point rail should be at least 8 to 13 millimeters (3/8 to 1/2 inch) above the bottom of the wheel flange and should rise to the full height of the flange as rapidly as possible. Special attention must be given if the wheel flange, in either the new or maximum-wear condition, has either a flat bottom or a sharp bottom corner. Such wheels can readily ride up the flat surface provided by the second machined cut in the AREMA 5100 switch point detail. If the light rail system employs such wheels, it may be necessary to use switch point details other than the 4000, 5100, and 6100 designs contained in the AREMA *Portfolio of Trackwork Plans* (see **Figure 6.5.8**).

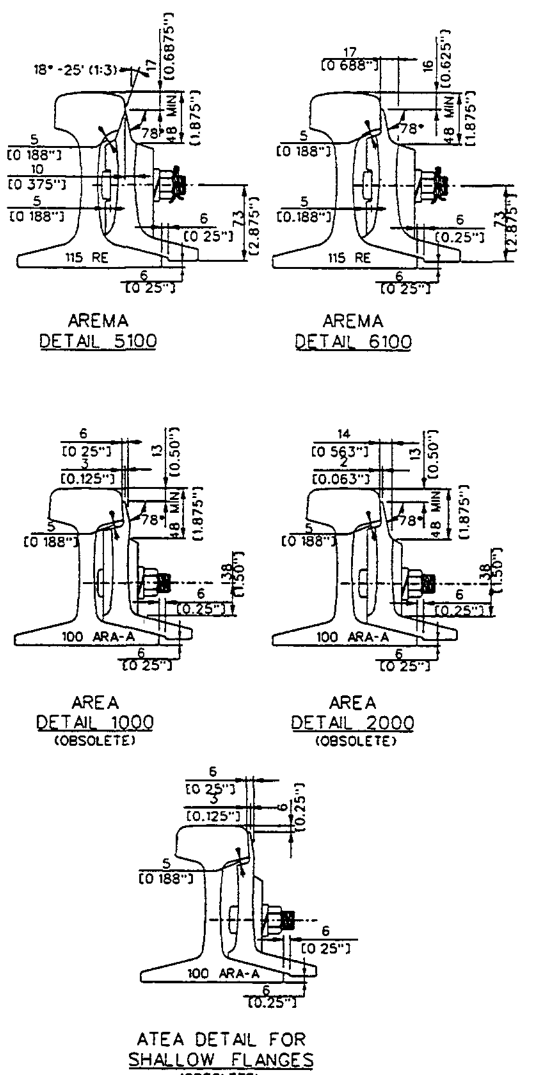


Figure 6.5.8 Switch Point and Stock Rail Details

The ATEA had a switch point standard for use with American Society of Civil Engineers (ASCE) rails that placed the top of the switch a mere 6 millimeters (1/4 inch) below the top of the stock rail as shown in Figure 6.5.8. These dimensions are not achievable with more modern rails that have broader gauge corner radii. Some light rail operations have reduced the distance between the wheel tread and the top of the switch point. This is accomplished by either grinding or planing away a portion of the head of the stock rail for a distance of approximately 300 millimeters (12 inches) ahead of and beyond the point of the switch. This "stock rail tread depression" lowers the relative position of the tip of the wheel flange so that it cannot easily climb on top of the point. The gauge corner radius of the stock rail is reduced to approximately 15 millimeters (about 9/16 inch) through the depressed area. While the stock rails with the depressed tread must be custom fabricated, this technique enables the use of off-the-shelf AREMA 5100 detail switch points. An alternate design where the undercut stock rail and switch point machining of the 5100 point detail actually places the switch point 1/4 to 3/8 inches below the top of the stock rail has recently been implemented to improve gauge point contact. For future transit design of switch points, a 7200 point detail number should be considered.

Trackwork designers on new systems should strongly encourage the adoption of wheel profiles with flange contours that are no less than 25 millimeters (1 inch) high. In addition to the above mentioned problems with switch points, short wheel flanges also concentrate the lateral component of the wheel-to-rail loading onto a narrower band than taller flanges. This higher contact pressure leads to accelerated wear on both wheels and rails. Refer to Chapter 2 for additional discussion on this topic.

6.6 FROGS

6.6.1 Frog Design

Track and vehicle design teams must carefully consider frog design in conjunction with the selection of a preferred wheel profile.

If the light rail vehicle wheel is generally identical to the AAR 1-B wheel, then frog designs can generally conform to AREMA standards as cited in the *Portfolio of Trackwork Plans.* Suggested revisions are noted below. Such frogs should comply with the following standards:

- Frogs in primary track can ordinarily be railbound manganese steel, heavy wall design, conforming to details given in the AREMA *Portfolio of Trackwork Plans*.
- Frogs in secondary track can be either railbound manganese steel or solid manganese steel construction conforming to the details given in the AREMA *Portfolio of Trackwork Plans*.
- Railbound manganese frogs tend to introduce more noise and vibration at the interface between the wing rail and the manganese irregular running surface. Joint LRT/railroad systems should consider solid manganese frogs with welded rail joints to eliminate irregularities in the rail surface to improve on reducing special trackwork noise.

Monoblock welded frog construction is extremely popular in Europe and has seen increased use in North America. Monoblock frogs have a central portion that is machined from a block of either rolled steel or cast steel that is metallurgically consistent with normal rail steel. Rolled steel rails are then welded to the central portion to form the frog arms This design can be advantageous for production of small quantities or one-of-a-kind frogs such as those required for crossing diamonds. See **Figure 6.6.1** for the arrangement of a typical monoblock frog.

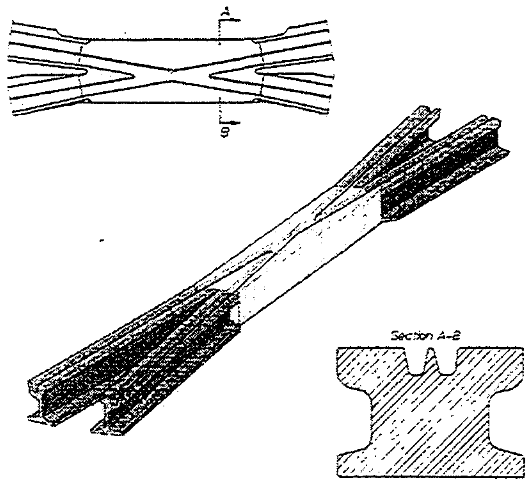


Figure 6.6.1 Monoblock Frog Details

6.6.2 Frog Design Modifications

Even if AREMA frogs are chosen, track designers should consider several modifications, including:

- Frog arms should be longer than the current (1997) AREMA standard to ensure that the toe and heel spreads are wide enough to permit field thermite welding. Additional length may be required to make it possible to crop off a failed thermite weld and make a second weld.
- Consideration should be given to depressing the point of frog slightly below the top of rail plane for a distance of approximately 100 millimeters beyond the actual point of the frog. This will minimize frog point batter from the wheel's gauge corner fillet, particularly on a transit system that features a compound radius wheel tread design, such as the AAR 1-B wheel (see **Figures 6.6.2** and **6.6.3**).

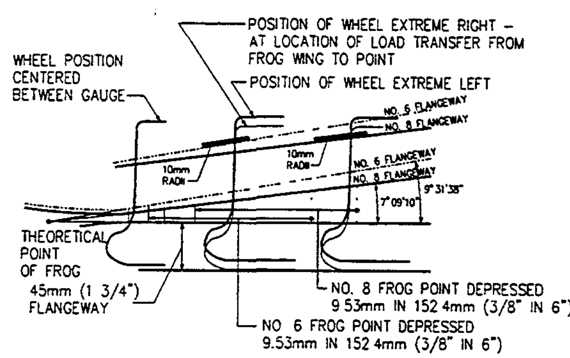


Figure 6.6.2 Plan View at Frog Area with 45-mm Flangeway

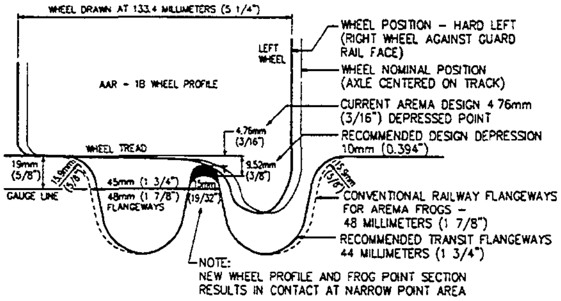


Figure 6.6.3 Section at 15-mm Frog Point

- If the light rail vehicle wheel has a tread that is less than 100 millimeters (4 inches) wide, it may not have continuous support while passing over the opposite flangeway of the frog. Excessive impacts can occur if the wheel tread has less than 25 millimeters (1 inch) of support width as it passes over the open flangeway, particularly if the operating speed is relatively high. If tight control can be maintained on both track gauge and wheel gauge, it is usually possible to correct this situation by narrowing the flangeway widths from the customary 48 millimeters (1-7/8 inches) to about 40 millimeters (1-9/16 inches) as shown in **Figures 6.6.3** and **6.6.4**).

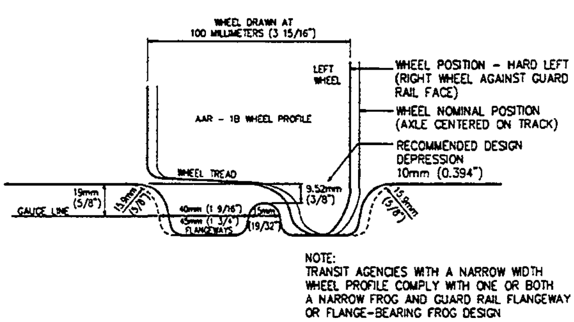


Figure 6.6.4 Section at 15-mm Frog Point, Flange Bearing

If open point frogs are not possible, then either flange-bearing frogs, spring frogs, or movable point frogs are needed.

6.6.3 Flange-Bearing Frogs

Flange-bearing frogs are typically provided whenever continuous wheel support cannot be provided by the wheel tread. This condition is most prevalent on light rail systems that employ a narrow wheel tread but also can occur on a transit system with wider wheels. Inadequate support often occurs in sharp angle frogs and crossing diamonds and is a universal problem as crossing frog angles approach 90 degrees. It can also occur at the mate opposite a tongue switch.

6.6.3.1 Flangeway Depth

Flange-bearing design carries the wheel load past the point of inadequate wheel tread support by transferring the load to the wheel flange tip. Typically, the tread is elevated a few millimeters above the normal top of rail elevation as this occurs. As the flangeway floor wears, equilibrium of both the flange and tread bearing may be achieved. This may or may not be acceptable depending on how uniformly the system's vehicle wheels are maintained. The depth of the flange-bearing portion of the frog should be 3 millimeters (1/8 inch) less than the nominal height of the LRV wheel flange. The flange-bearing section should extend longitudinally from about 300 millimeters (12 inches) ahead of the theoretical frog point to a location 200 millimeters (8 inches) beyond the actual frog point (see Figure 6.6.4) to ensure that the wheel is carried well past the point of non-tread support.

6.6.3.2 Flangeway Ramping

The wheel flanges on most rail systems tend to get higher as the wheels wear since the wheel tread experiences virtually all of the wheel wear. In order for a flange-bearing frog to accommodate normal maintenance tolerances in wheel flange height, there must be a transition ramp from the ordinary flangeway depth of perhaps 50 millimeters (1-7/8 inches) to the flange-bearing depth. The slope of this ramp should be varied depending on the desired vehicle speed so as to minimize the impact. A taper as flat as 1:60 is not unusual in situations where a flange-bearing frog is used in a main line track. As a guideline, the ramp ratio should be no steeper than 1 divided by twice the design speed in kilometers per hour

6.6.3.3 Flange-Bearing Frog Construction

Flange-bearing frogs are typically fabricated as solid manganese steel castings or welded monoblocks. Hardened steel inserts have also been used in bolted rail frog construction. The center manganese steel insert in a railbound maganese (RBM) frog may not be long enough to obtain ramps of appropriate length for typical transit operating speeds.

Flange-bearing frogs tend to develop a wheel wear groove in the floor of the flangeway that can steer the wheels. If one side of the frog is only used rarely, this groove can become deep enough to possibly cause wheel tracking problems when a vehicle passes through the rarely used flangeway. Flange-bearing frogs may therefore require additional flangeway floor maintenance, including grinding away sharp edges and occasional welding to build up the groove.

6.6.3.4 Speed Considerations at Flange-Bearing Frogs

The support between the wheel flange and the flangeway floor can cause moderately disagreeable noise and vibration. For this reason, flange-bearing design is usually limited to relatively slow speed operations (less than 25 k/hr is common). The 1998 revisions to the Track Safety Standards of the U.S. Federal Railroad Administration (FRA) recognizes flange-bearing design for the first time, but limits operation over such frogs to FRA Class 1 speeds of 16 k/hr freight and 24 k/hr passenger (10 mph freight and 15 mph passenger). While the FRA standards do not apply to most rail transit operations, they will in segments of light rail systems where railroad freight operations are permitted. If any flange-bearing construction is considered for joint use areas, system designers should be aware that the operating speed of both freight and light rail passenger equipment will be restricted by federal mandate. If such speed restrictions compromise the transit system's operations plan, it may be necessary to forgo flange-bearing design and adopt other approaches to provide wheel support.

6.6.3.5 Wheel Flange Interface

A light rail system with a minor amount of flange-bearing special trackwork can typically use a conventional wheel contour with a rounded flange. On the other hand, if there is a significant amount of flange-bearing special trackwork, a rounded flange tip tends to flatten due to wear and metal flow under impact. This results in flanges that are shorter than design, which in turn could cause problems at switch points. If a large amount of flange-bearing specialwork is expected, consideration should be given to a wheel flange design that is flat or nearly flat on the bottom. This will minimize the likelihood that wheel flanges will experience damaging metal flow from traversing flange-bearing frogs. Refer to Chapter 2, Figure 2.6.5F, for a typical wheel design intended for use with flange-bearing special trackwork.

It is important for track designers to recognize that when an LRV wheel is running on a flange tip, its forward velocity is slightly greater than when it is operating on the wheel tread even though the rotational velocity in terms of revolutions per unit time is unchanged. Thus, if one wheel is running on its flange and the other wheel on the same axle is rolling on the tread surface, the flange-bearing wheel will attempt to travel slightly further ahead. This condition cannot persist for long before wheel slip will force both wheels to resume their normal orientation opposite each other. This is rarely a problem provided that each axle is independently powered. However, if the LRV truck design powers both axles from a single motor ("monomotor" truck design) flange-bearing design can introduce loadings that may overstress mechanical portions of the LRV drive train as one wheel attempts to travel further than the other three to which it is rigidly connected. Failures of gearbox connections between the axles and the monomotors have been common and vehicle manufacturers in part blame flange-bearing special trackwork. To minimize this problem, some European track designers include a flange-bearing grooved head girder rail opposite any flange-bearing frog.

6.6.4 Spring and Movable Point Frogs

When continuous support is required and flange-bearing design is not appropriate due to operating speed or other conditions, either spring frogs or movable point frogs can be considered. Such components are costly, high maintenance items and should be used only when unavoidable. If the system includes tracks where high vehicle speeds are required, system designers should seriously reconsider whether the use of narrow wheel treads is advisable.

6.6.5 Lift Over ("Jump") Frogs

Any frog will generate noise and vibration, which can be an environmental concern at many locations. In locations where an embedded turnout is used only very infrequently, such as an emergency crossover, some light rail systems have employed what is known as either a "lift over" or "jump frog" (see **Figure 6.6.5**)

A jump frog provides a flangeway only for the main line movement. When a movement occurs on the diverging route, the frog flangeway and wing rail portion is ramped up to a level that allows the wheel to pass over the main line open flangeway and running rail head. To protect the direction of the raised wheel, a restraining guard rail is provided on the opposite wheel. The lift over action will introduce noise and vibration comparable to a flange-bearing frog. However the more frequent straight through main line movements will have a continuous wheel tread support and the overall amount of street noise attributable to the light rail system will be reduced.

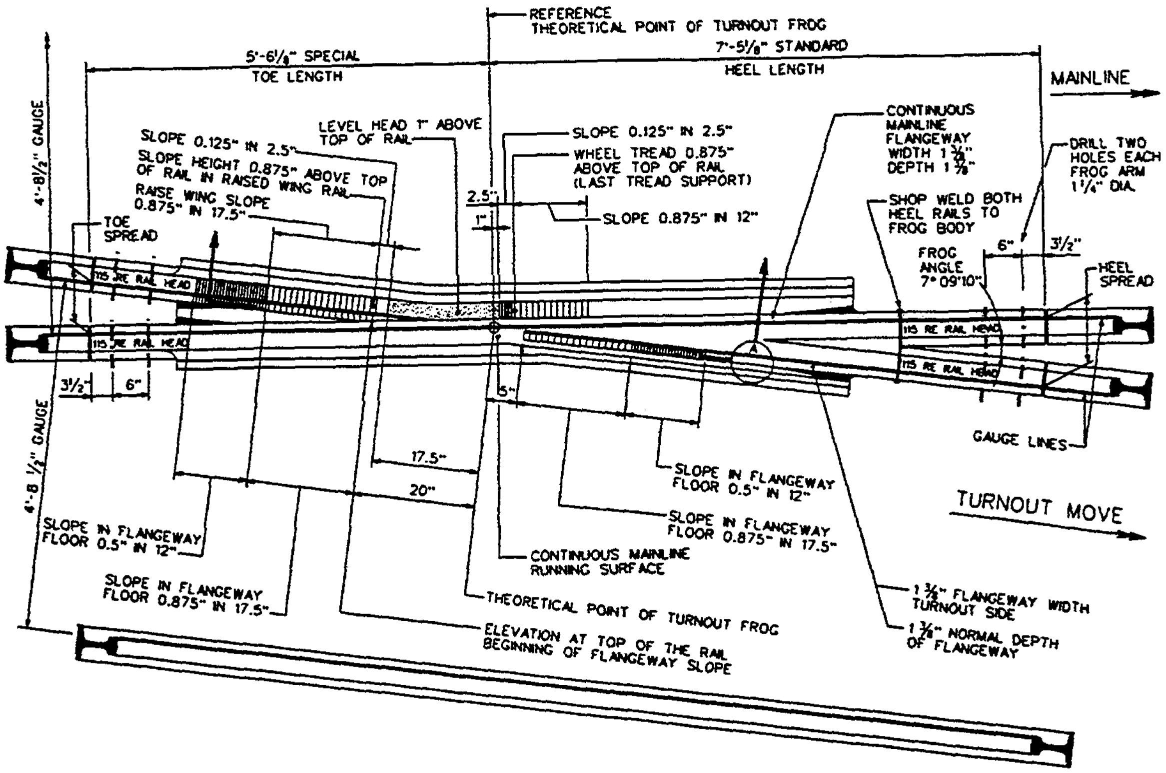
6.6.6 Frog Running Surface Hardness

Regardless of frog design, the portions of the frog that support the wheels should have a minimum surface hardness of 385 BHN. This can either be inherent in the material from which the frog is fabricated or achieved by post-fabrication treatments such as explosive hardening. If flange-bearing design is employed, the flangeway floor should also be hardened.

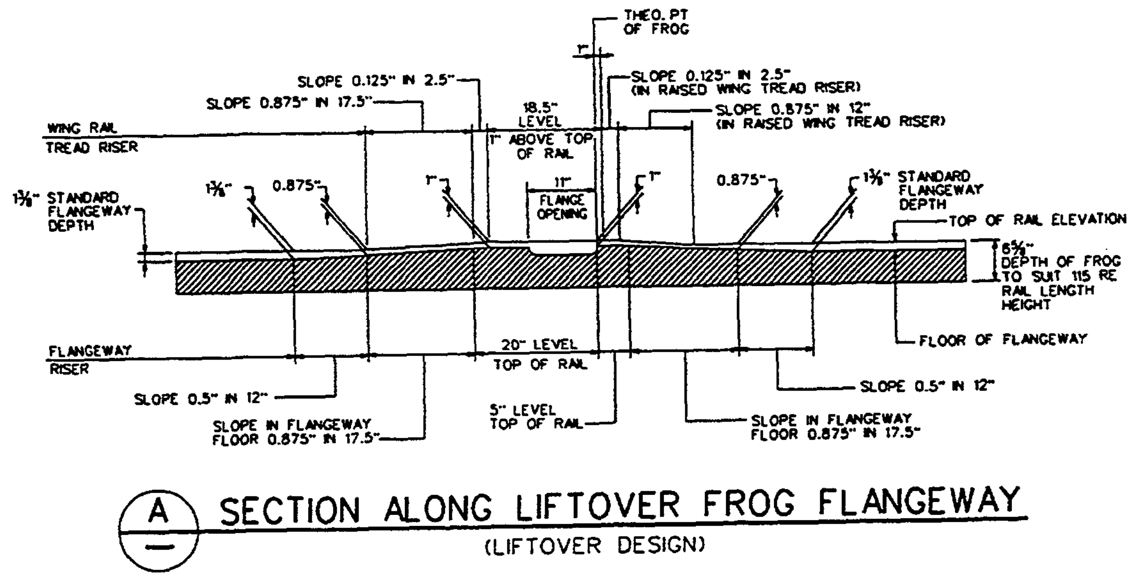
6.7 FROG GUARD RAILS

Guard rails must be installed opposite from frog points both to protect the fragile frog point and to prevent wheel flanges from tracking on the wrong flangeway through the frogs.

If transit wheel gauge standards are followed, it may be necessary to provide a very narrow



NO. 8 TURNOUT FROG - LIFT OVER DESIGN- RIGHT HAND (SHOWN)



SECTION ALONG LIFTOVER FROG FLANGEWAY

(LIFTOVER DESIGN)

Figure 6.6.5 Lift Over Frog Design

guard rail flangeway in order to ensure that the wheel flange remains in the proper path through the frog. Widened track gauge may be required. Guard rails should extend ahead of the point of frog for a distance not less than that given in the AREMA *Portfolio of Trackwork Plans.* They should extend beyond the frog point to at least the location of the heel end of the frog wing rail. Where the closure curve radius of the turnout is sharp enough that curve guarding is required, the required restraining rail system and the frog guard rail on the diverging side of the turnout should be continuous.

Frog guard rails should be adjustable and generally compatible with the restraining rail design adopted for the project.

Installing an adjustable guard rail in embedded track is difficult; therefore traditional street railway operations typically installed a section of girder guard rail in lieu of a conventional guard rail. Some contemporary embedded track installations provide a segment of U69 guard rail fastened to chairs in a manner that nominally permits adjustment (provided that the fastenings do not become corroded and unusable). If the guard rail cannot be adjusted in the installed environment, complete removal and replacement of both the pavement and the guard rail may be required. In addition, frog guard rail rarely need adjustments if properly installed. Designers should carefully consider whether frequent guard rail wear is likely before selecting a complex design that may have limited value.

6.8 WHEEL TREAD CLEARANCE

Throughout any special trackwork unit, it is important to be certain that nothing projects above the top of rail plane into a zone where it might be struck by the outer edge of the LRV wheel tread. The designer must not only consider the as-new width of the wheel tread, but also the allowable wear limits on both the side of the wheel flange and on the gauge line of the rail as well as any allowable metal overflow on the outer edge of the wheel. Wheel tread clearance will rarely be less than 125 mm (5 inches) except for systems with narrow wheel treads. For additional information on wheel profiles refer to Section 2.6.4.

6.9 SWITCH TIES

While domestic hardwoods are the most popular materials for North American switch ties, significant advances have been made in the design of concrete switch ties. Particularly on any system that elects to use concrete crossties for main line ballasted track, consideration should be given to the employment of alternative materials for switch ties.

Tropical hardwoods from forests in Africa and South America, such as Azobe, Jarrah, and Quebraco, were briefly popular in North America for switch ties and crossties in special applications. They have fallen out favor in recent years due to environmental concerns relative to rain forest depletion and unsatisfactory experiences that some railroads and transit agencies have had with these products. They remain in common use, however, on railways and transit systems in countries that do not have large hardwood forests.

Trackwork designers must consider requirements for stray current control when choosing the type of switch tie to be used. If insulated installations are required, the designer must consider the dielectric properties at each rail seat and the switch plate must be evaluated on both timber and concrete switch ties. For more information on rail seat insulation refer to Chapter 5.

Concrete switch ties can improve the stability of turnout and crossing installations and will provide a track modulus comparable to main line concrete crosstie track. Concrete switch ties must be individually designed to fit at each specific location within a turnout. Hence, a concrete switch tie designed for use at a particular location in a No. 6 turnout will likely not be usable in a No. 10 turnout. However, because of their size—they generally are 250 millimeters (10 inches) wide—concrete switch ties require a spacing layout that is distinctly different from that used with timber switch ties. The new tie layout can impact turnout switch design by requiring alternate switch rod positions. The two ties at the point of switch area that support the switch machine must remain at the 559-millimeter (22-inch) AREMA standard center distance if they are to accommodate power standard North American switch machines. **Figures 6.9.1** and **6.9.2** illustrate typical Number 8 and 10 concrete tie ballasted turnouts using SI units. For addition information on switch ties, refer to Chapter 5.

6.10 RESTRAINING RAIL FOR GUARDED TRACK

As noted in the beginning of this chapter, the broad definition of special trackwork includes restraining rail systems for guarded track. For details concerning these topics refer to the following:

- For additional information on guarded trackwork, refer to Chapter 4.
- For addition information on restraining rail designs for guarded track, refer to Chapter 5.

When curves with restraining rails are adjacent to turnouts and track crossings, the track designer should consider integrating the restraining rail into the turnout by design to avoid makeshift connections between them in the field.

6.11 PRECURVING/SHOP CURVING OF RAIL

Precurved rail is also considered special trackwork since shop fabrication or special processing is required to bend the rail steel beyond its elastic limit.

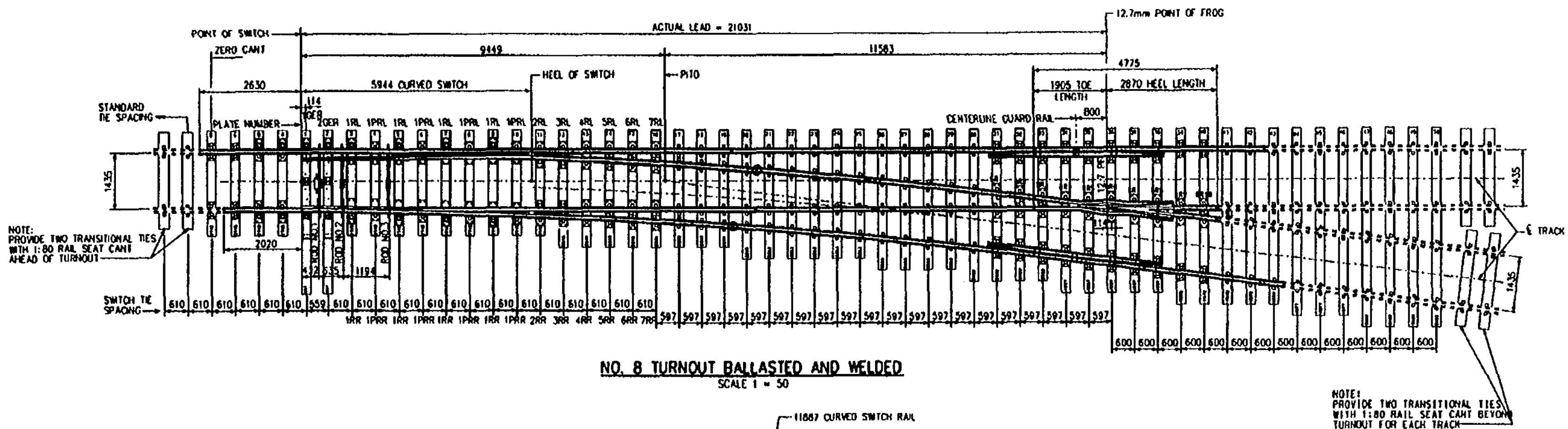
6.11.1 Shop Curving Rail Horizontally

For additional information on precurving of tee rail and girder groove rail refer to Chapter 5.

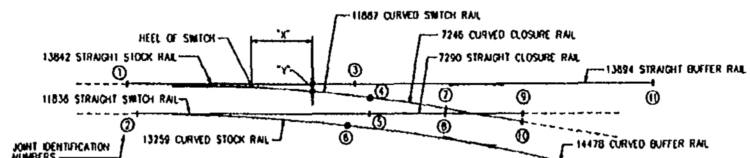
6.11.2 Shop Curving Rail Vertically for Special Trackwork

If a special trackwork unit is within a vertical curve, as often happens when embedded trackwork must conform to existing street geometry, it may be necessary to shop curve rails vertically so that they lay uniformly without kinked joints or welds to adjoining rails. This is particularly true when it is necessary to field weld adjoining rails.

An 1189-mm (39-foot) long 115 RE rail is supported only at its ends, can assume a sag vertical radius of about 1524 meters (5,000 feet). A similar crest radius can be achieved by a rail supported only in the center. These equate to a mid-ordinate deflection of about 25 mm (1 inch) over the length of the rail. If the requisite vertical radius is sharper than this, the rails should be shop curved vertically to avoid assembly problems in the field. Technically, the shapes assumed by such simply supported rails are neither circular curves nor parabolic curves, but are close enough for practical field purposes.



NO. 8 TURNOUT BALLASTED AND WELDED
SCALE 1 = 50



RAIL LAYOUT DIAGRAM
NOT TO SCALE

NO. 8 BALLASTED TURNOUT	
QTY.	DESCRIPTION
1 ASSY.	SPLIT SWITCH 5944 mm WITH UNIFORM RISERS, COMPLETE
1 ASSY.	No. 8 RBM HEAVY WALL FROG, COMPLETE
2 ASSY.	ADJUSTABLE GUARD RAIL SET 132 RE 4600 mm , COMPLETE
1	CURVED CLOSURE RAIL, 7278 mm Lg.
1	STRAIGHT BUFFER RAIL, 13893 mm Lg.
1	CURVED BUFFER RAIL, 14474 mm Lg.
1	STRAIGHT CLOSURE RAIL, 7245 mm Lg.
2	INSULATED JOINT KITS
1	SET OF FROG PLATES 8R1 TO 8R10 (RHTO)
2	SPECIAL TIE PLATE TP1
2	SPECIAL TIE PLATE TP8R
156	SPRING CLIP, PANDROL TYPE
1 SET	ONE COMPLETE SET OF TURNOUT TIES (54)
	TRANSITION TIES (1:80) - (6 PER TURNOUT)

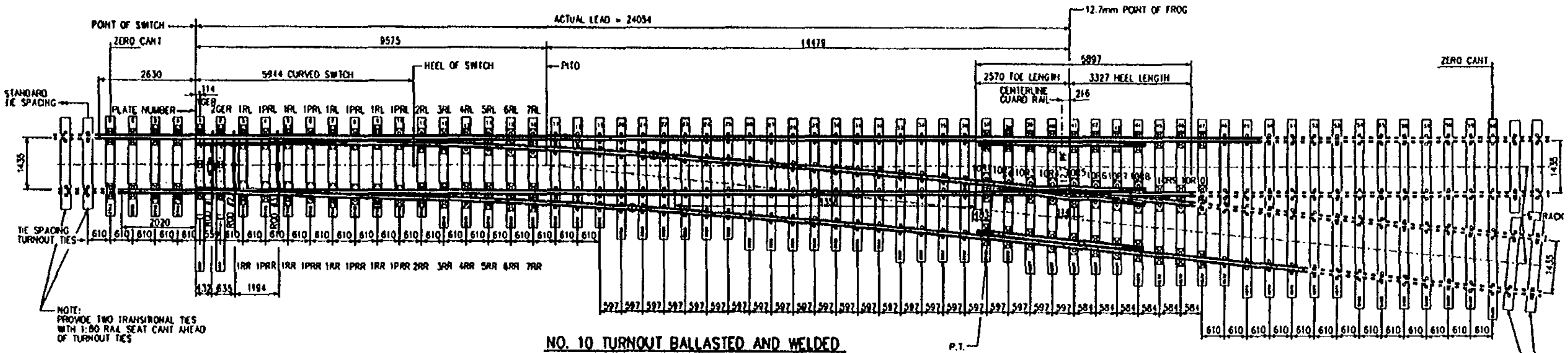
TURNOUT DATA		
FROG	NUMBER	8
	ANGLE	7°09'15"
	TOE LENGTH	1905
	HEEL LENGTH	2870
	TOTAL LENGTH	4775
	TOE SPREAD	225
	HEEL SPREAD	371
SWITCH	LENGTH OF SWITCH	5944
	THICKNESS OF POINT	0
	HEEL ANGLE	1°59'15"
	HEEL SPREAD	159
	ANGLE AT POINT	1°04'24"
	VERTEX DISTANCE	0
	RADIUS	372,517
ACTUAL LEAD		21,031
CENTERLINE RADIUS		145,432
TANGENT AT TOE OF FROG		0
TANGENT AT HEEL OF SWITCH		

BILL OF MATERIAL	
CONCRETE SWITCH TIES	
LENGTH	QTY.
2743	13
3048	8
3353	6
3658	4
3962	4
4267	7
4572	5
4877	3
5182	4
TOTAL	54

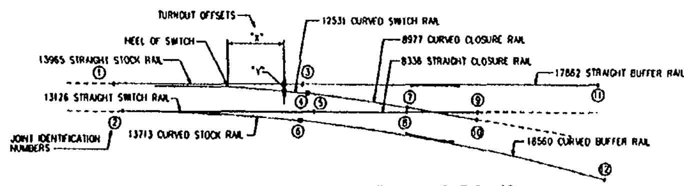
NOTES:

1. LEFT HAND TURNOUT SHALL BE OPPOSITE TO THAT SHOWN.
2. RAIL AND COMPONENTS CONFORM TO THE 115 RE RAIL SECTION.
3. ALL RAILS INDICATED BY SOLID LINES IN RAIL LAYOUT DIAGRAM ARE HIGH STRENGTH RAIL.
4. DASHED LINES IN RAIL LAYOUT DIAGRAM INDICATE CONTINUOUS WELDED RAIL (STD OR HEAT TREATED) BEYOND TURNOUT RAIL. RAIL INDICATED BY DASHED LINES ARE NOT INCLUDED IN THE BILL OF MATERIAL ON THIS DRAWING.
5. CLOSURE RAIL LENGTHS ALLOW 7/8" FOR EACH THERMITE WELD.
6. CONCRETE TIE FASTENINGS SHALL BE FURNISHED FOR ALL TIES WHERE SPECIAL PLATES ARE NOT REQUIRED. INSULATION MAY BE REQUIRED.
7. ALL SPECIAL TRACKWORK TURNOUT PLATES REQUIRE INSULATION.

Figure 6.9.1 No. 8 Turnout—Ballasted Concrete Ties with 5944 Curved Switch



NO. 10 TURNOUT BALLASTED AND WELDED
SCALE 1 = 50



RAIL LAYOUT DIAGRAM
NOT TO SCALE

NO. 10 BALLASTED TURNOUT	
QTY.	DESCRIPTION
1 ASSY.	SPLIT SWITCH 5944 mm WITH UNIFORM RISERS, COMPLETE
1 ASSY.	NO. 10 RBM HEAVY WALL FROG, COMPLETE
2 ASSY.	ADJUSTABLE GUARD RAIL SET 132 RE 4600 mm, COMPLETE
1	CURVED CLOSURE RAIL, 8977 mm Lg (DRILLED ONE END)
1	STRAIGHT BUFFER RAIL, 17862 mm Lg.
1	CURVED BUFFER RAIL, 18560 mm Lg. (DRILLED ONE END)
1	SET OF FROG PLATES 10R1 TO 10R12
1	STRAIGHT CLOSURE RAIL, 8336 mm Lg.
2	INSULATED JOINT KITS
1	SET OF FROG PLATES 10R1 TO 10R10 (RHTO)
3	SPECIAL TIE PLATE TP1
2	SPECIAL TIE PLATE TP10R
3	SPECIAL TIE PLATE TP1
3	SPECIAL TIE PLATE TP10R
360	SPRING CLIP, PANDROL TYPE
1 SET	ONE COMPLETE SET OF TURNOUT TIES (64)
	TRANSITION TIES (1:80) - (6 PER TURNOUT)

TURNOUT DATA		
FROG	NUMBER	10
	ANGLE	5°43'29"
	TOE LENGTH	2570
	HEEL LENGTH	3327
	TOTAL LENGTH	5897
	TOE SPREAD	244
	HEEL SPREAD	345
SWITCH	LENGTH OF SWITCH	5944
	THICKNESS OF POINT	0
	HEEL ANGLE	1°59'15"
	HEEL SPREAD	159
	ANGLE AT POINT	1°04'24"
	VERTEX DISTANCE	0
	RADIUS	372 517
ACTUAL LEAD		24 054
CENTERLINE RADIUS		245 696
TANGENT ADJACENT TO TOE OF FROG		- 483
TANGENT AT HEEL OF SWITCH		

BILL OF MATERIAL	
CONCRETE SWITCH TIES	
LENGTH	QTY.
2743	13
3048	8
3353	6
3658	7
3962	6
4267	7
4572	5
4879	5
5182	6
5486	1
TOTAL	64

NOTES:

1. LEFT HAND TURNOUT SHALL BE OPPOSITE TO THAT SHOWN.
2. RAIL AND COMPONENTS CONFORM TO THE 115 RE RAIL SECTION.
3. ALL RAILS INDICATED BY SOLID LINES IN RAIL LAYOUT DIAGRAM ARE HIGH STRENGTH RAIL.
4. DASHED LINES IN RAIL LAYOUT DIAGRAM INDICATE CONTINUOUS WELDED RAIL (STD OR HEAT TREATED) BEYOND TURNOUT RAIL. RAIL INDICATED BY DASHED LINES ARE NOT INCLUDED IN THE BILL OF MATERIAL ON THIS DRAWING.
5. CLOSURE RAIL LENGTHS ALLOW 7/8" FOR EACH THERMITE WELD.
6. CONCRETE TIE FASTENINGS SHALL BE FURNISHED FOR ALL TIES WHERE SPECIAL PLATES ARE NOT REQUIRED. INSULATION MAY BE REQUIRED.
7. ALL SPECIAL TRACKWORK TURNOUT PLATES REQUIRE INSULATION.

Figure 6.9.2 No. 10 Turnout—Ballasted Concrete Ties with 5944 Curved Switch

In extremely sharp horizontal curves, it will be necessary to account for rail cant when bending the rails. This requires that the rails be cambered vertically prior to horizontal bending

6.12 PROPRIETARY SPECIAL TRACKWORK DESIGNS AND LIMITED SOURCES OF SUPPLY

Many of the innovative transit-specific special trackwork designs developed by European fabricators are not produced by North American special trackwork manufacturers. Some of these designs are proprietary, but, in general, North American special trackwork manufacturers have been disinterested in undertaking the investment necessary to satisfy the limited demand for such products. Instead, they concentrate on the materials customarily required by their largest customers—North American freight railroads. The trackwork designer must carefully consider the prudence of designing a system where essential trackwork products will be difficult to obtain at reasonable cost through competitive bidding. Use of sole-source products or proprietary designs should generally be avoided. Because complex interrelationships can exist between the various elements of the overall trackwork design, this evaluation should be performed before design details are selected and procurement and construction contracts are advertised. The designer should also consider whether the same products or interchangeable substitutes are likely to be available for future maintenance and expansion of the system. Caution is recommended if special trackwork sources are limited solely to overseas manufacturers or a single domestic supplier.

Regardless of the source of supply, special trackwork units should be standardized to the maximum degree possible so that economies of scale are possible during both initial project construction and subsequent long-term maintenance. One-of-a-kind assemblies should be avoided.

6.13 SHOP ASSEMBLY

Special trackwork layouts, particularly complex layouts involving more than one turnout, should be preassembled at the fabrication shop. This will enable inspectors to verify that all components fit together as specified and are in accordance with approved shop drawings. Any allowable deviations from the approved shop drawings should also be noted on assembly plans so that field installation crews can make any necessary adjustments to the trackwork.

During shop assembly all components should be fully assembled ready for installation in the field. The only exception would be insulated joints that are glued during field installation, which can be assembled dry in the shop. If crossties and rail fastenings are to be furnished with the layout, they should be installed during shop assembly. If timber switch ties are included as a part of the assembly, they can be permanently preplated during the shop assembly, particularly if elastic rail fastenings are being used.

6.14 REFERENCES

[1] American Railway Engineering and Maintenance of Way Association, *Manual for Railway Engineering*, 1964.